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POWER MEASUREMENT AND PROFILE USING PC

LIM ZI JIE

This thesis is submitted in partial fulfillment of the requirements for the awarding of Degree in Bachelor of Electrical Engineering

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Dedicated, in huge gratitude to my beloved father, mother, sisters and lover for their care, understanding and encouragement

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Lastly, I felt grateful to have you all with me, thanks again for all the help and support that I needed.

ABSTRACT

Power measurement is no longer an unfamiliar phrase among people and industries. No matter they are researchers, electric companies, factories or common people, they are doing power measurement at all time. Researchers need to do some analysis on the field of electrical power, electrical companies need to optimize their generators and calculate the tariff, factories need to monitor their power usage and power factor and common people need power measurement to know how many power that had been used throughout the year. This project aims to create a device to measure the power of equipment and to monitor the power profile for a long time. This power measurement device created is based on the data acquisition concept using PIC microcontroller and USB interface. Software is developed to control the device and to show the result is created using Visual Basic Language. The system had been run and tested part by part before the whole system is being combined and implemented. A benchmark is also done using the commercial power meter to measure the actual power of the equipment used in the tests and then compare with the result obtained from the system developed. The result shows that there is some error due to the system speed is not fast enough to cater the requirement to produce an accurate result.

ABSTRAK

Pengukuran kuasa bukanlah suatu ungkapan yang baru kepada manusia dan industri. Tak kira mereka adalah ahli kajian, kompani elektrik, kilang-kilang mahupun rakyat biasa, mereka turut membuat pengukuran kuasa pada setiap masa. Ahli kajian perlu membuat analisis dalam bidang electrik, kompani elektrik perlu mempertingkatkan keupayaan penjana dan membuat pengiraan tariff, kilang-kilang perlu memantau kegunaan kuasa dan faktor kuasa dan rakyat biasa perlu mengetahui berapa kuasa yang telah digunakan dalam masa setahun. Projek ini bertujuan untuk menghasilkan suatu alat untuk mengukur kuasa sesuatu alatan dan memantau profil kuasa untuk jangka masa yang panjang. Alat pengukuran kuasa ini dicipta berdasarkan konsep pengambilalihan data menggunakan PIC dan USB. Perisian dihasilkan untuk mengawal alatan dan memaparkan keputusan dengan menggunakan bahasa *Visual Basic*. Sistem ini telah dioperasikan dan diuji bahagian demi bahagian sebelum seluruh sistem ini digabungkan. Suatu pembandingan juga dijalankan dengan menggunakan meter kuasa yang ada dalam pasaran untuk mengukur kuasa sebenar alatan yang diuji. Keputusan yang didapati terdapat sedikit kekurangan disebabkan kelajuan sistem adalah terhad.

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LIST OF SYMBOLS

P	-	Power
PF	-	Power Factor
V	-	Volt
W	-	Watt
A	-	Ampere
Hz	-	Hertz
dw	-	rate of change of power
dq	-	rate of change of charge
C	-	Coulomb
J	-	Joule
I	-	Current
dt	-	rate of change of time
V_m	-	maximum voltage
I_m	-	maximum current

LIST OF ABBREVIATIONS

PIC	-	Peripheral Interface Controller
USB	-	Universal Serial Bus
AC	-	Alternate current
DC	-	Direct current
ADC	-	Analog to digital converter
RAM	-	Random Access Memory
ROM	-	Read Only Memory
I/O ports	-	Input/ output ports
EEPROM	-	Electrical Erasable Programmable Read Only Memory
RS-232	-	Recommended Standard 232
IEEE	-	Institute of Electrical and Electronics Engineers
GUI	-	Graphical User Interface
IDE	-	Integrated Development Environment
HID	-	Human Interface Device
PID	-	Product ID
VID	-	Vendor ID
RMS	-	Root mean square

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CHAPTER 1

INTRODUCTION

1.1 Background

Power measurement is important from research area to domestic houses. It is used in all kinds of field especially in the electrical engineering. Power measurement is useful in measuring the power consumption of a house or factory, thereby knowing its rate of power consumption each day or monthly and hence be able to make plans to conserve electric usage or to know the power used by each machine. As for the electrical supplier, the generation sector need to know the power produced by their generators while for transmission and distribution sector, they need to know how much electrical power is needed to install suitable transformer to give constant and uninterrupted electricity.

Until today, many kinds of power measuring method and equipment had been invented. From the conventional analog wattmeter using D'arsonval meter and electrodynamometer to advanced digital wattmeter, power measurement technique is improving day by day. The improvement of the power measurement is scaled by the increasing ability of giving accurate result in a short time. Availability and handling difficulties also give impacts to the quality of the power measuring device. As the technology in science and industry is flourishing, more advance and fast power measurement equipment is needed in the industry and research area. In many kinds of applications, data need to be collected and stored for further uses such as research and analysis. Common method of storing data is not efficient and involved a lot of handwriting which waste a lot of time and resources.

1.2 Problem Statement

Although there was a lot of advanced power measurement equipment available in the market, however, the trade-off of these sensitive and powerful tools is the cost. To build sensitive and powerful equipment, it needs better components and they are more expensive, hence increasing the total cost of power measuring.

Besides that, some of the equipment needs a complicated connection or a lot wires and cable connect to the load in order to measure the power and shows the results. A more complex procedure and careful steps as well as tests and precaution need to be made to ensure that the system is well designed. This had brought inconvenience to the user in his/her power measuring process.

In most of the time, we need not only to acquire the values for the power measured but also to store the result and data from time to time. Data storing is very important for further references and analysis for further usage. Conventional method requires us to copy data one by one using handwriting and this process are slow and not efficient. Besides, it also limits us in terms of the interval that we can acquire data, which means that we are unable to store the data fast enough and affect our work. In any way, data storing using conventional methods are troublesome and sometimes frustrating.

Other than that, for constant reading and to check the condition of a load, the profile of the load needs to be monitored in a clear diagram and must be able to do it in short time. Except some sophisticated machines, there are rarely cheaper and reliable equipment for doing so.

1.3 Objectives

The main objective of this project is to design and create a device to measure the power through a load by using personal computer (PC) as measurement tool and to monitor the power profile. The objectives of the project also includes measuring the rms voltage, rms current, power factor and average power of the electrical appliances, to create a software used to calculate and show results of the measured parameters, to use PIC and USB port as the interfacing devices as well as to plot the voltage, current and power profile of the load. Computer is a very powerful calculator and is able to receive data and the process it in lightning speed. By using computer, data can also be easily stored without much effort. These data can be called at anytime and the result can be monitor with just a few clicks on the keyboard. An accurate graph can be plot instantly and show on the screen with ease.

1.4 Scope

The scope of the project includes:

- Write a program using programming language Visual Basic to calculate and show data such as voltage, current, power factor and power through load and its power profile
- Design a circuit to convert the single phase analog voltage and current to digital signal using PIC and transducers
- Create a circuit to allow load or equipments to connect to the circuit system to be measured
- Implement the designed circuit system into hardware and interfacing the hardware to computer using USB ports
- The system is for domestic uses which the voltage rating is 230V and $5A<I<30A$

1.5 Methodology and Approach

The overview of the methodology and approach of the project is shown below. Careful planning and steps had been suggested and information had been gathered in producing the required steps to achieve the objective of the project. The project is been divided into two parts which consist of Interface and Hardware design. Interface Design can be further divided into Hardware Part and Software Part. Below are the steps that must be taken to complete the project.

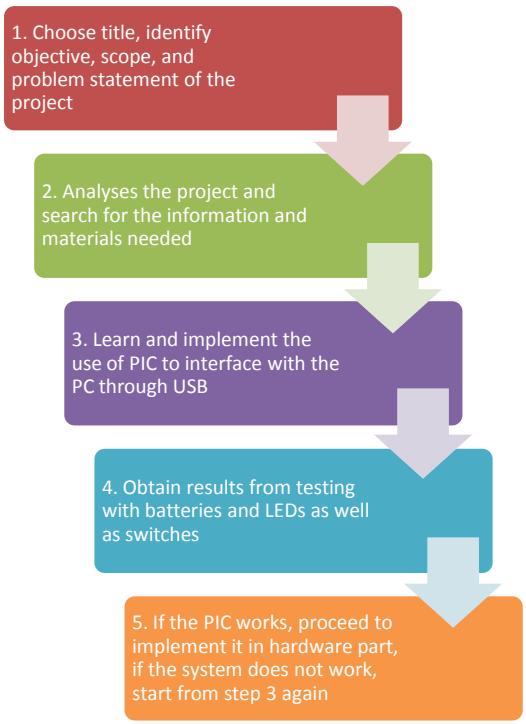
1. Choose title, identify objective, scope, and problem statement of the project
2. Analyses the project and search for the information and materials needed
3. Learn and implement the use of PIC to interface with the PC through USB
4. Obtain results from testing with batteries and LEDs as well as switches
5. If the PIC works, proceed to implement it in hardware part, if the system does not work, start from step 3 again

Figure 1.1 Hardware Part (Interface)

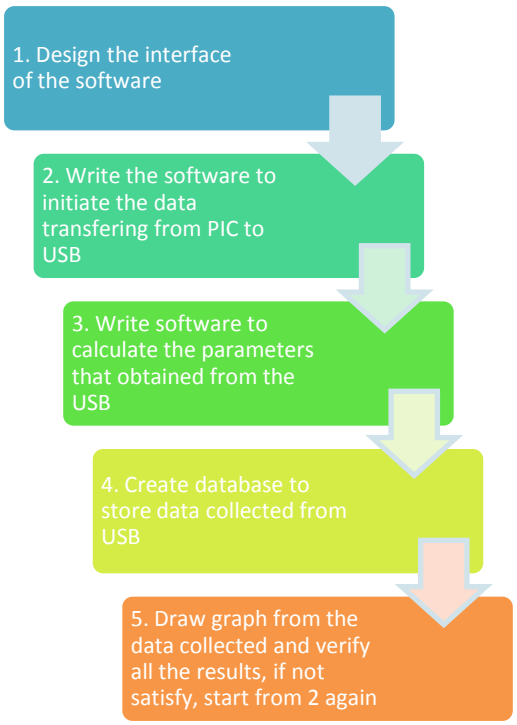
1. Design the interface of the software
2. Write the software to initiate the data transfering from PIC to USB
3. Write software to calculate the parameters that obtained from the USB
4. Create database to store data collected from USB
5. Draw graph from the data collected and verify all the results, if not satisfy, start from 2 again

Figure 1.2 Software Part (Interface)

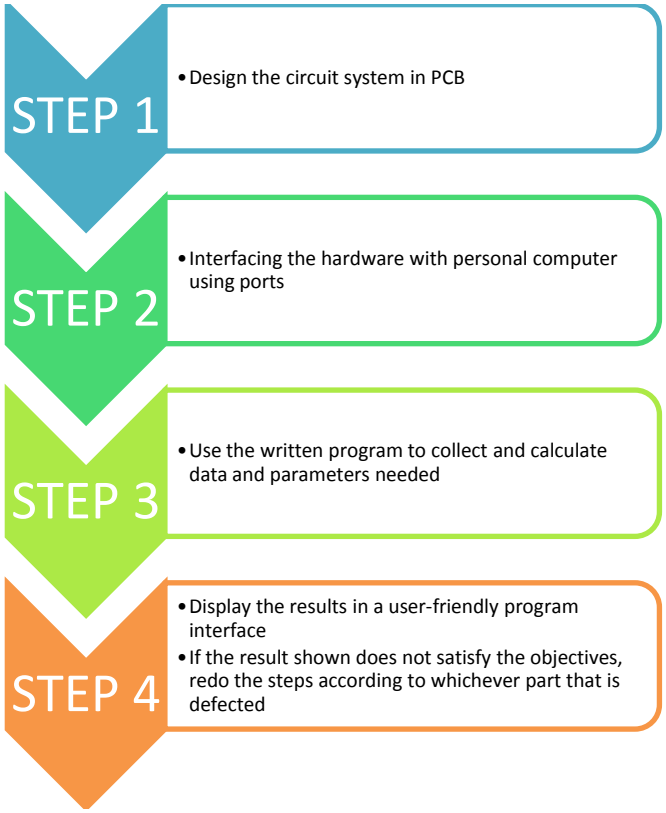
STEP 1
• Design the circuit system in PCB
STEP 2
• Interfacing the hardware with personal computer using ports
STEP 3
• Use the written program to collect and calculate data and parameters needed
STEP 4
• Display the results in a user-friendly program interface
• If the result shown does not satisfy the objectives, redo the steps according to whichever part that is defected

Figure 1.3 Hardware Design

1.6 Gantt Chart of FYP-1

Activity/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Decide title of project		/	/	/	/										
Define objective					/	/									
Define scope					/	/									
Searching for information					/	/	/	/	/	/	/	/	/	/	
Drafting methodology								/	/	/	/				
Analysis of components										/	/	/			
Analysis of equipment										/	/	/			

Learning programming software											/	/	/	/	/
Preparing for presentation										/	/	/	/		
Preparing FYP1 report														/	/

Figure 1.4 Gantt Chart FYP 1

1.7 Gantt Chart of FYP-2

Activity/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Learn and program the PIC	/	/	/	/	/	/	/								
Develop software for interfacing and power calculation	/	/	/	/	/	/	/	/	/	/	/	/	/	/	
Preparing components for hardware implementation				/	/	/									
Design the hardware circuit in protoboard and test to get the result				/	/	/	/								
Build the circuit system					/	/	/	/	/	/	/				
Obtain a few sample result and finalized						/	/	/	/	/	/	/	/	/	
Complete the													/	/	/

FYP-2 report and presentation slides															

Figure 1.5 Gantt Chart FYP 2

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses about the theory and concept of power measurement, different power measurement equipment and techniques developed throughout the history and core components of ADC. The work related to this project will also be discuss in the further part of this chapter to give a brief idea how the whole system will work and an early preview of the expected result.

2.2 Power Measurement Theory

To know how to measure the power, we must first know its parameter that forms it. Voltage or potential difference is the energy required to move a unit charge through an element measured in volts (V). By mathematically derivation,

$V_{ab} \triangleq \frac{dw}{dq}$, where V_{ab} is the voltage between two points a and b, w is the energy in joule (J) and q is the charge in coulombs (C). In this term, the voltage also can be interpret as the work that is required to move a unit charge from point a to point b in an electric circuit, given the potential at point b is lower than the potential at point b.

Current is the rate of change of charge measured in amperes (A). The relationship between charge q, current I, and time t can be express in mathematical equation as follow:

$I \triangleq \frac{dq}{dt}$, where I is the current in ampere, q is charge in coulomb and t is time in second. Given 1 ampere is equal to 1 coulomb/second. There are two types of currents, one is which the current remains constant at all time that we called direct current (DC) and another one is called alternate current (AC) where its current changes sinusoidally with time.

Power is the time rate of expending or absorbing energy, measured in watts (W). The relationship of power with voltage and current is given by:

$P = \triangleq \frac{dw}{dt} = \frac{dw}{dq}.\frac{dq}{dt} = vi$, where P is power in watt (W), w is energy in joule and t is time in second. For direct current and voltage, the above expression for power persists. However, nowadays, we use alternating supply in domestic as well as most transmission and distribution sector. Therefore, in terms of AC power, the instantaneous power at anytime varies and average power is used to measure the power through a load. Average power can be express as the average of the instantaneous power over one period of time. The mathematical expression of average power, $P_{avg} = \frac{1}{T}\int_0^T p(t)\,dt = \frac{1}{2}V_m I_m \cos((\theta_v - \theta_i)$, where T is the period of a cycle, V_m is the maximum voltage, I_m is the maximum current and $(\theta_v - \theta_i)$ is the phase difference of voltage and current. The cosine of phase difference can also be stated as the power factor of the system [1], [6].

2.3 Conventional Power Measurement Equipment

2.3.1 D'Arsonval Galvanometer

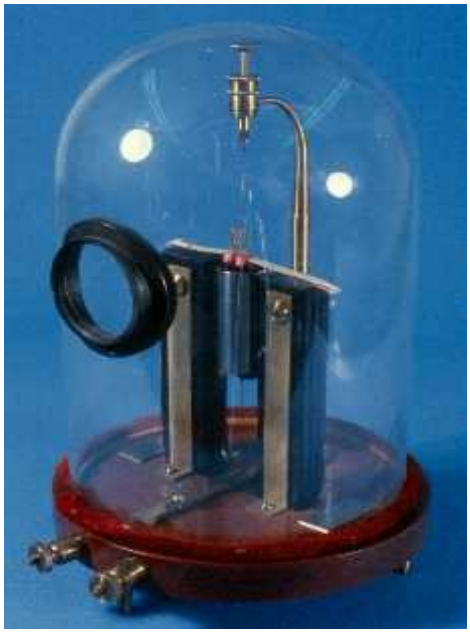

Figure 2.1 D'Arsonval meter at the University of Toronto

D'Arsonval Galvanometer was invented by two Frenchmen in the early 1880s, who were Jacques D'Arsonval (1851-1940) and Marcel Deprez (1843-1918). Jacques was born in La Porcherie worked as a professor of experimental medicine as well as the director of a biological physics laboratory. Marcel on the other hand was born in Aillant-sur-Milleron and he was an electrical engineer. Both of them had developed the galvanometer with permanent magnet and moving coils which is suspended by flat ribbon of wires. At the lower end of the coil, the connection is supplied by a light and helical spring. This spring is used to give the restoring torque so that it will return to original position. From the Ohm's Law developed by Georg Ohm which states that the voltage across a conductor is directly proportional to the current through it, measurement of voltage and current can be made and hence power can be obtained. To be able to do this, the electromagnetic torque produced by the moving coils and magnet is proportional to the current in the coil and the restoring torque is proportional to the angle of twist of the suspension fiber. At equilibrium

state, the current flowing through it is directly proportional to the angle of deflection. Scales can then be made to acquire the voltage [2].

The form of D'Arsonval galvanometer today is built with a coil of wire in surrounding the permanent magnet. The magnet produces magnetic field and this magnetic field will act against the magnetic field produced by the coil when current flows through the coil. The coil will be twisted due to this action and will push against the spring which is connected to the meter pointer. The pointer will points to the value of the current or voltage measured [3].

2.3.2 Electrodynamic Meter

Electrodynamic meter consists of a pair of fixed coil known as current coil and a movable coil which is the potential coil. The potential coil which connected in parallel with the circuit carries a needle that moves over a scale to show the measured value. The current coils that are connected in series with the circuit generate electromagnetic field around the coil when current flows through it and the strength of the magnetic field is proportional to the line current and in phase with it. Because of such an arrangement, the deflection of the needle is proportional to the both the current and voltage leading to the equation P=VI in a DC circuit. Whereas in an AC circuit, the deflection of the needle is proportional to the average instantaneous product of voltage and current, and hence the real power that we needed is measured [4].

2.3.3 Electrodynamometer

Electrodynamometer was invented by Werner von Siemens (1816-1892) in the early 1880s. Siemens was an electrical businessman as well as an inventor. Siemens had used the principal that was published by Wilhelm Weber (1804-1891) which states that when the same current passes through two concentric coils placed at

right angles to each other, the resulting torque depends on the square of the current in his paper in 1848. In Siemens invention, there were stationary coils which made of a few turns of heavy wires and a rotating coil which made of many turns of fine wires. The stationary coil is connected in series with the circuit while the rotating coil is connected across the load. A multiplier resistance is connected in series with the load to allow measurement of voltage to be done. Therefore, the power on a load is measured by taking the current passing through the coils times with the voltage drop in the load [5].

2.3.4 Electronic Wattmeter

Figure 2.2 One of the latest wattmeter available

An electronic wattmeter is a small digital power measurement tool which is capable of measuring power with ease and accurately as it display real digital values [4].

2.4 Reviews from Journals

2.4.1 Data Acquisition System

In today, we are required to monitor a lot of system so that to know the parameters, the effects of a change done to a system, to know the reliability and constrain of a system, to do analysis of certain control system and much more. For examples, a soft drink production factory need to control the rate of flow of the water into the cans and a thermal power plant needs to control the heat of the boiler so that the power plant can effectively generate the required amount of power. To be able to do these, a data monitoring and acquisition system must be made to obtain the data and to do analysis on the data logged somewhere, whether handwritten or directly copied into computers or other equipment. Most of the data that we obtain directly from the external world is in analog form. As digital system is rapidly developed, many of these analog data have to be converted into digital form in various ways. One of the easiest ways is to use an analog to digital converter.

However, this is still not enough. Most of the data acquisition system contains its own unique circuit or machine, which every output must be shown in within the interface of the machine only. Although in some machines, the data can be exported through external disk, this process will take time and is not efficient as we had to continuously copy data from the machine and read it in our own computers. Otherwise, some devices provides direct linking through traditional port such as parallel and serial port which is rarely available in a more portable computer, that is a laptop. We do not want to carry our huge home desktop computer wherever we wanted to work. Hence a more portable and flexible data acquisition system must be produced. To make the operations autonomous and efficient, a microcontroller can be used in the system. A microcontroller is flexible electrical equipment that provides lots of function according to what we tell the microcontroller to do. It can control from small electrical circuit to a robot or a large system depending on our applications.

In the year 2004, M.Popa, an IEEE member, M. Marcu and A.S. Popa had proposed a data acquisition system using microcontroller. Furthermore, the system uses USB as the interfacing device. They selected the P89C51RD2 microcontroller as the core of the system. The microcontroller will control the USB interface device to receive and send data by using the interrupt from the microcontroller. The USB interface, ISP1181 is using USB 1.1 specifications and is connected directly to the microcontroller. Two TLC0820 ADCs are solely controlled by software created in the computer. When signal is sent from the microcontroller to tell the USB interface to initiate its operations, the USB interface will start receiving data from the data bus. Before anything can be received, the ADCs must be activated first in the software. Because the ADCs do not require control signals from the microcontroller, therefore the speed of conversion is faster and will be able to directly send the converted signal into the 16 bit data bus of the microcontroller and USB interface. Then the data will be sent to the computer through the USB ports to show in the software [13].

Another suggestion from Yanpeng Wang and Mingming Fu about the data acquisition system using microcontroller with USB interface device was made in the year 2010 in WASE International Conference on Information Engineering. The main idea was to create a portable data acquisition device by implementing USB ports. To obtain high-speed data acquisition and to meet the real time requirements, the conventional method of data transmission is too slow to realize the concept of the project. The data transmission using parallel port is complicated and expensive. Even by using RS232 serial port, the speed is relatively slow. With the emergence of USB protocols, all these limits had been broke off.

The system developed by the two China people uses ADC0820, PDIUSBD12 USB interface and AT89S51 microcontroller as the main system components. ADC0820 is an 8-bit analog to digital converter and it received the output signals from the sensors. The ADC will then convert the signal into digital form with the command from the host via microcontroller. Later, the microcontroller will activate the conversion process of ADC and received the digital signal from the ADC. After that, it will transmit the data through PDIUSBD12 to the computer. The software

created using LabVIEW software developed by National Instruments will act to store and display the data collected. LabVIEW provide a graphical programming environment mostly needed by the engineers and scientists who want to do measurement, graphical plotting and analysis using the data from the external devices. LabVIEW can also interact with other development software such as Matlab and C Languages. The advantages of this method used are the GUI of the interface and data presentation is good and the information can be stored for further analysis [14].

Almost similar data acquisition system based on USB also been developed by Bi Bo, Sun Shuyung and Wang Chunping in the year 2007 and was published in The Eighth International Conference on Electronic Measurement and Instruments. Using USB protocol allows intercommunication between peripheral devices and plug-and-play services. Plug-and-play services provide the users to easily connect or disconnect the device without problem of damaging the USB device or installing before used. Various speeds can be chosen including Low Speed, Full Speed and High Speed depending on the applications.

In the design, an interface circuit and a function circuit was combined to form the whole circuit system. The interface circuit is used to link the computer and the function circuit together while the function circuit collect the signals from the equipment and send it to the interface circuit. The EZ-USB chip was used to communicate with the ADC of the system. When the system operates, the external analog signal will be sent to the sample-holding circuit. The signal will be process by the ADC chip, MAX197 and after the conversion process is completed, the data will be transferred to the USB interface chip and then to the PC application software. The equipment was used to detect an industrial-control system and the project gave high stability and precision [15].

In the paper published by Dmytro Titkov, Volodymyr Shvaichenkoa and Olena Shvaichenko, the use of microcontroller with USB interface was again proved the significant advantage in data acquisition and controlling system. USB protocol was used as small computer models such as laptop does not support RS232 or

parallel port. In order to allow communication with the PC, PIC with USB support is still the best way to implement the required system. It is many times much cost effective than using method other than mentioned above [16].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project is divided into two phase that is interface design and hardware design. Interface design phase focus on designing a workable circuit to connect the hardware part to the interface part and then create a software as the interface for the whole circuit system. Therefore, the Interface Design can be split up into two parts which is Hardware Part and Software Part. Hardware Part of the Interface Design is responsible for designing a circuit using PIC and Bridge Rectifier to collect data from the Hardware Design and to convert the analog signal to digital signal so that the computer can read the data transferred. It also filters out the negative phase of the sinusoidal signal which the PIC cannot receive. The Software Part is to create an interface using Visual Basic to do all the calculations of parameter after received from the PIC and then display and save the data and results collected. Hardware Design phase is to create a circuit system using voltage and current transducer as their main components in to convert the high voltage and current into the range where the PIC could handle.

Below is the block diagram of the whole circuit system:

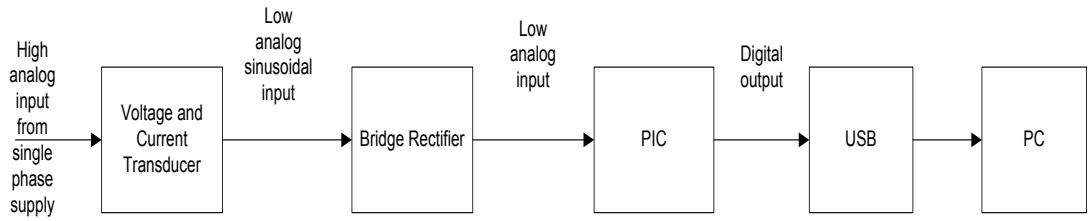

Figure 3.1 Block diagram of the whole circuit system

3.2 Hardware Design

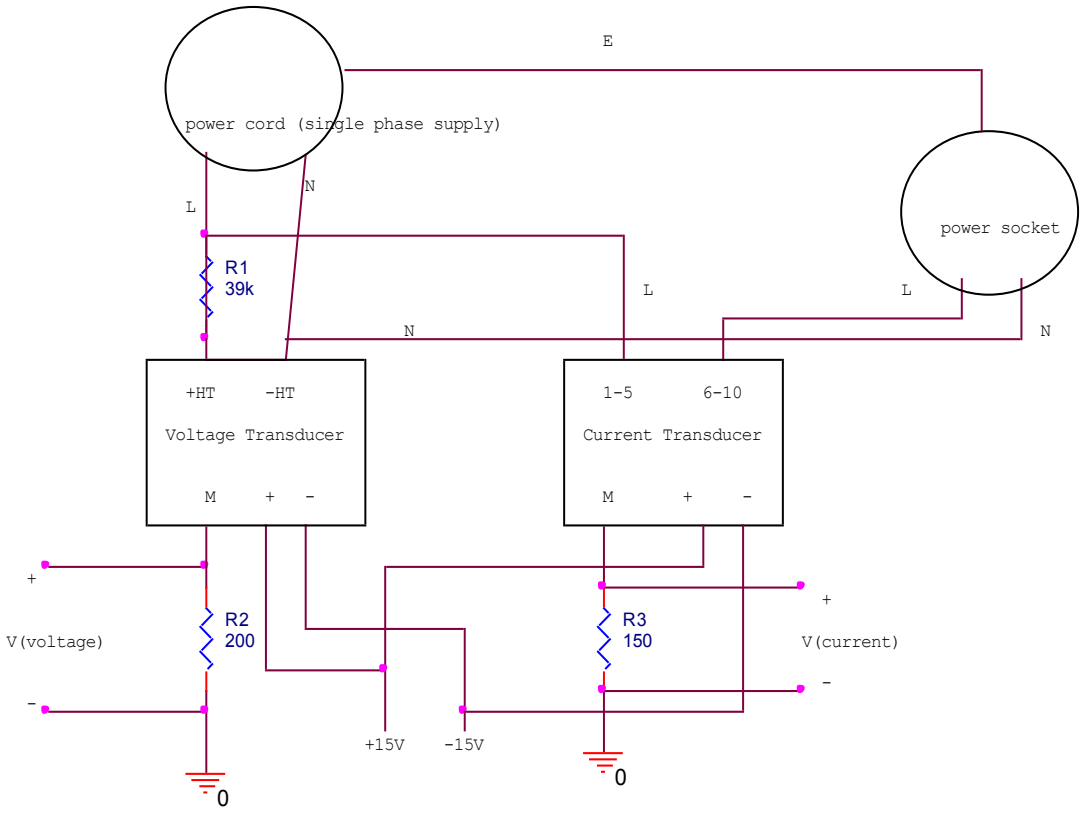

Figure 3.2 Schematic of the hardware design

3.2.1 Voltage Transducer

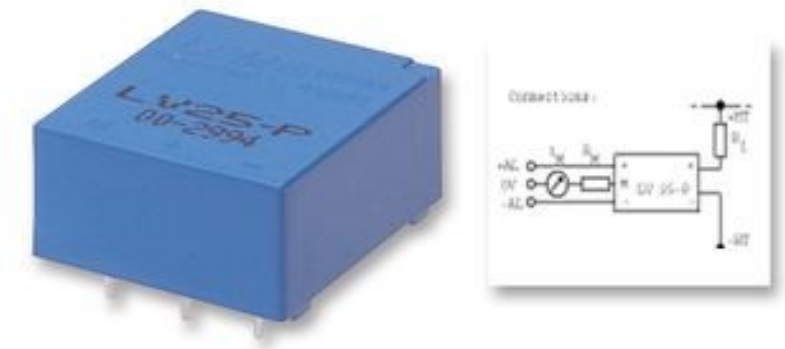

Figure 3.3 Voltage Transducer LV 25-P

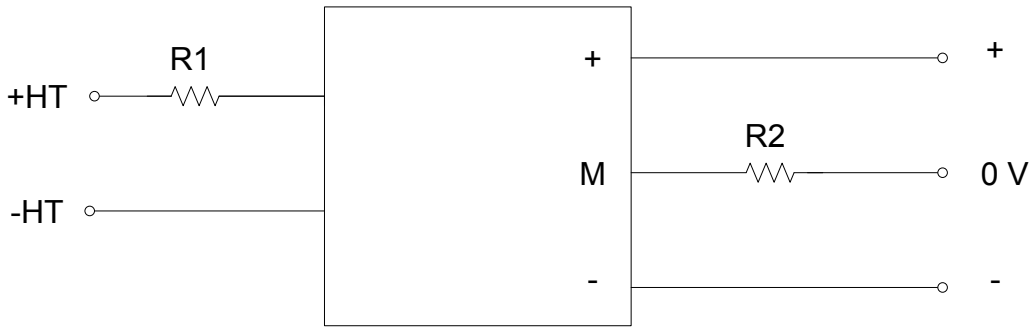

Figure 3.4 Connection of LV 25-P

A voltage transducer is a special type of transformer where they convert the primary voltage to secondary voltage almost the same phase with the primary voltage. The ratio of the primary voltage to secondary voltage is a known constant which changes very little with load. Therefore it is suitable to be use in measuring and monitoring the voltage on a system without having to interrupt the system. The low voltage output at secondary also enables us to operate measuring equipments and tools at low voltage [6].

The model of voltage transducer that is used in this project is LV 25-P, which is a closed loop Hall Effect transducer. Hall Effect transducer uses the changes in magnetic field to control the output voltage of the transducer. The general advantages of this voltage transducer including high bandwidth, low thermal drift, good linearity, high accuracy, immunity to external interference is high and disturbance in common mode is low. The primary nominal rms current is 10 mA while the primary nominal

rms voltage is in the range of 10 to 500 V. The secondary nominal rms current is 25 mA with a conversion ratio of 2500:1000. In order to operate the voltage transducer, it needs a supply voltage of ±12 to 15 V connected to the + and – pins. The voltage transducer carries the responsibility to convert the high voltage from the supply which will be around 230 V rms and to a lower value of voltage according to our needs. In this case, the range of voltage that is needed is within 0 to 5 V peak to peak. In order to measure a voltage, a current that is proportional to the measured voltage must be passed through an external resistor R1, which must be selected to fit the range of voltage that we need. The resistor is then connected in series with the primary circuit of the transducer. Then a secondary resistor, R2, must be connected in series with the secondary circuit through pin M of the voltage transducer, to obtain the converted voltage. The output voltage will be the voltage across the resistor, R2 due to the linear relationship between voltage and current at constant resistance.

In order to acquire best accuracy from the voltage transducer, the voltage to be measured must first be identified. This is because the nearer the primary input current to the primary nominal current, which is 10 mA, the higher the accuracy.

3.2.2 Current Transducer

Figure 3.5 Current Transducer LA 25-NP

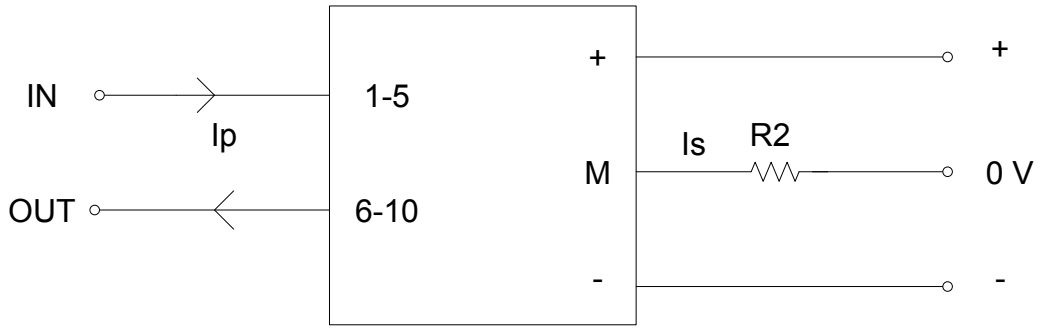

Figure 3.6 Connection of LA 25-NP

Current transformer/transducer is a transformer that converts the primary current proportionally to secondary current, with negligible phase change, normally less than one degree. In this case, we can use it to monitor and measure the current in a line isolated from the primary circuit [6].

A current transducer is used to measure and convert the input current from single phase supply so that PIC will be able to read the values. LA 25-NP is the model of the current transducer used in this project. It is like the twin brother of LV 25-P which carries almost identical features and advantages with it. It is also a Hall Effect transducer with galvanic isolation between the primary circuit and secondary circuit. The primary nominal rms current is 25 A while the secondary nominal rms current is 25 mA with conversion ratio of 1-2-3-4-5:1000. Depending on the conversion ratio, the primary nominal rms current ranges from 5 to 25 A suit different needs of the users. Because to obtain accurate results from the current transducer, the input current must first be determined first so that the conversion ratio and hence the primary input current will be in the range of the primary nominal current. To choose different setting for the conversion ratio, the connections of the IN and OUT pins of the transducer must follow the recommended connections in the datasheet provided. IN pins which consist of pin 1 to 5 is connected to the primary circuit while the OUT pins from pin 6 to 10 is connected to the equipment to be measured. Just like its twin brother, LA 25-NP also requires ±15 V to activate the electronics circuit inside the transducer. They are connected to the + and – pin of the transducer.

A resistor R3 is connected to the M pin of the transducer and the voltage across R3 will be measured as the output voltage. This output voltage will then be calculate and revert back to obtain the actual input current by using the proportionality relationship of voltage and current.

3.2.3 Bridge Rectifier

2 bridge rectifiers which the model name is KBP402 is connected to the output of from both the voltage and current transducer to filter out the negative signal of the sinusoidal waveform. PIC18F4550 that we used in the project can only receive positive voltage signal and hence the rectifiers plays a vital role in the conversion process. The outputs voltage from current and voltage transducer is feed into the 'AC' pins of the bridge rectifier while the output after rectified from + pin and – pin is connected to the input port of the PIC and ground respectively.

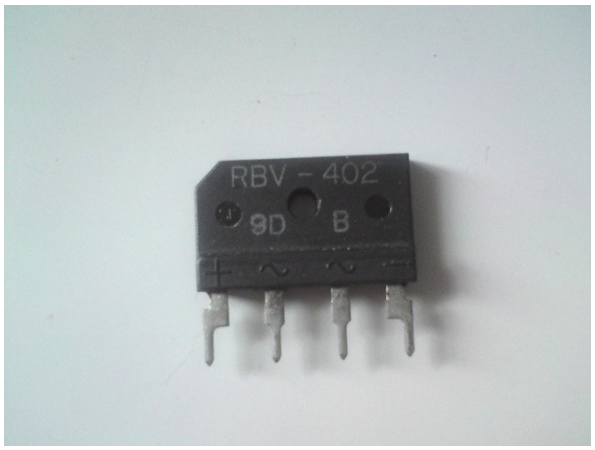

Figure 3.7 Bridge rectifier

3.2.4 Power Cord and Socket

Figure 3.8 Power cord and socket

A power cord is used to provide the single phase supply from the main socket to the whole circuit system as well as to the equipment to be measured. The power socket provides a stand to the electrical equipment to draw the power supply required to operate. In this project, domestic load is used and hence a regular 3 pins 13 A power cord and socket is used. The life wire will be connected to the input of the voltage and current transducer while the neutral wire is connected with only the voltage transducer. This will form a parallel connection to the voltage transducer so that the voltage of the load can be measured. The output of the current transducer will connect to the power socket to form series connection with the life wire to obtain the current flows in the load.

3.3 Interface Design

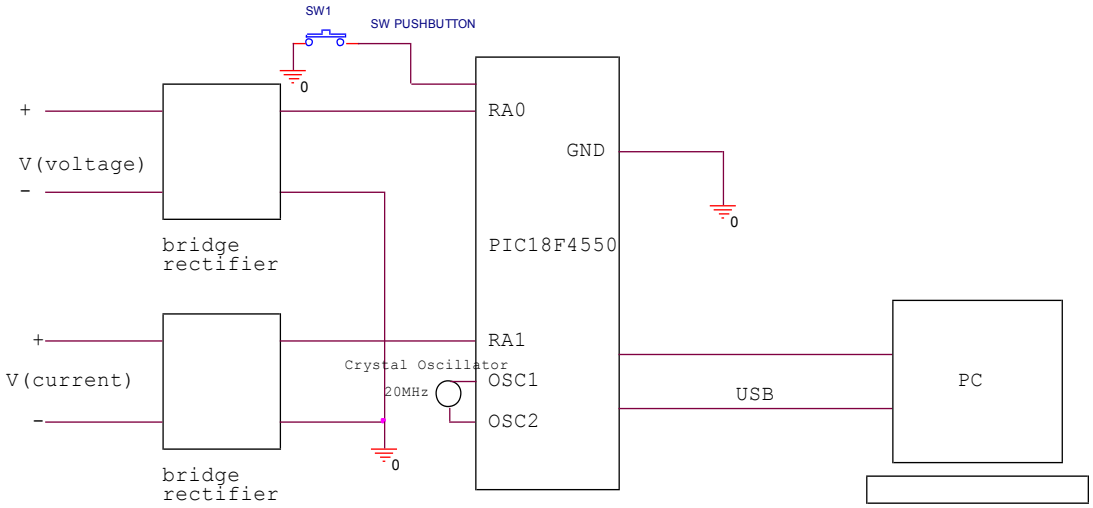

Figure 3.9 Schematic of the interface design

3.3.1 Hardware Part

3.3.1.1 Peripheral Interface Controller (PIC) Microcontroller

Figure 3.10 PIC Microcontroller

Figure 3.11 Microprocessor

PIC microcontroller can be considered as a category of the microprocessor. Microprocessor such as Pentium 4, Core 2 Duo and now i7 is very high in performance with extremely fast processing speed. Microprocessor is a standalone microchip and it cannot do anything on its own. It requires additional peripheral such as Random Access Memory (RAM), Input and Output Ports (I/O ports), Read Only Memory (ROM) and others to function as a system. Unlike the microprocessor, although a microcontroller is not as fast as a microprocessor, but it contains all the components needed to be able to function on its own. The microcontroller have build-in RAM, ROM, a number of I/O ports, Timer, USB ports, Serial ports depending on the type and model.

Microcontroller can be found everywhere in our electronics devices such as washing machine, video games, DVD player, refrigerators and in most of the more "intelligent" machines. This is because the size of the microcontroller itself and the flexibility to program it to do the job we wanted.

In a microcontroller, there are many types of memories. ROM is one of the basic memories in a microcontroller. Read only memory, as its name suggest, can only be read and the data inside the memory is fixed. The memory is being programmed during manufactured and cannot be deleted even power is removed from the ROM. Therefore, the users can only use the sole function provided by the manufacturer.

Random Access Memory (RAM) is a volatile memory that allows data to be read and write continuously. A volatile memory does not retain its data when power supply is removed from it. RAM comes in different size.

Electrical Erasable Programmable Read Only Memory (EEPROM) is yet another type of memory in a microcontroller. It is a non volatile memory and the data can be erased and reprogram using external programming devices. EEPROM is slow memory and only used to save basic configuration information and programming functions in it.

A supply voltage must be applied to a microcontroller for it to operate. +5 V is mostly used in the microcontroller with some tolerance. The microcontroller contains its own instruction set. The users must use the instruction set available in order to program the microcontroller. Not all the instruction set for every microcontroller is the same. Therefore the users must study what is available for them before starting to write the program in it.

There are a number of Input and Output ports (I/O ports) available for users to program and use them. Some of the ports are analog or digital or both, depending on the initiation done in the firmware. They can be input port or otherwise output port. Users no longer needed to worry about the insufficient of input or output ports and buy another microcontroller to cater with ports that is fixed on the type [7].

i) PIC18F4550

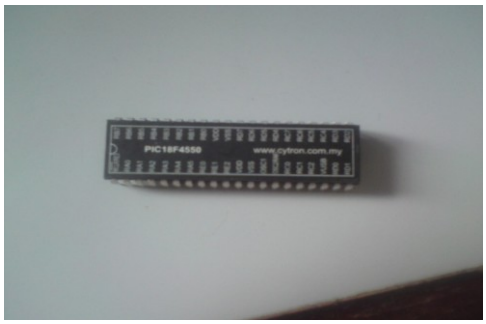

Figure 3.12 PIC18F4550

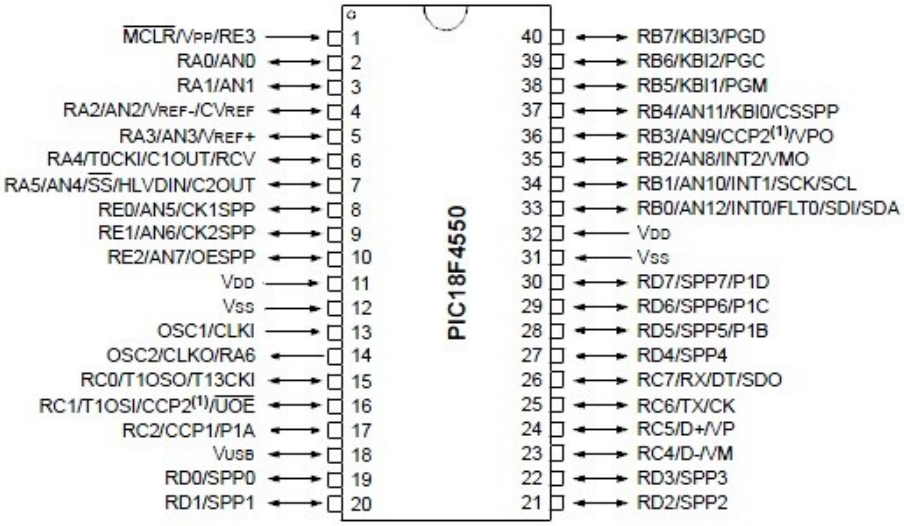

Figure 3.13 Pinouts of PIC18F4550

PIC18F4550 is the core of the interfacing design, or perhaps the whole project. The microcontroller act like the brain of the whole system, receiving all the data from the hardware circuit and then process the data before sending it to the computer. The reason why PIC18F4550 is chosen is because of several reasons:

a) USB support, which means that we no longer need to use a RS-232 converter if we wanted to connect it to the PC
b) Being able to delete and rewrite the firmware easily lasted for up to one million time
c) Bootloader can be use to allow programming of the PIC need not have to constantly removing it to the programming socket and put the PIC back to the circuit system after programmed
d) There is also a build in 10-bit 13 channel analog to digital converter (ADC) in the PIC so that the users do not need to have an external ADC to convert the analog signal to digital signal
e) Multiple input and output ports in a single microchip

Unlike regular microchip, a PIC microcontroller must first be programmed in C languages before it contains any functions. C language is a common programming language learnt in Electrical Engineering courses. After being programmed, the ports

that are already activated will be able to receive input and provide the output required. The pins that are involved in this project are shown in the table below:

Table 3.1: Pins used in project

Pin Name	Pin No.	Description
MCLR	1	Reset when high
RA0	2	Analog input of V(voltage)
RA1	3	Analog input of V(current)
OSC1	13	Connect to oscillator
OSC2	14	Connect to oscillator
GND	31	Ground of the whole system
RB0/SW1	33	The PIC will operate when button is pressed
D+	24	USB data +
D-	23	USB data -

3.3.1.2 Analog to Digital Converter (ADC) in PIC18F4550

The integrated ADC in the PIC is 10-bit in size and has a total of 13 channels. There are 5 registers in the ADC which is A/D Control Register 0 (ADCON0), A/D Control Register 1(ADCON1), A/D Control Register 2(ADCON2), A/D Result High Register (ADRESH) and A/D Result Low Register (ADRESL). The first control register, ADCON0 is used to control the operation of the A/D module while ADCON1 works to set the functions of the port pins. ADCON2 is the register that configures the acquisition time and A/D clock source. These registers are extremely important and must be configures properly or the ADC will not work as needed. Both the ADRESH and ADRESL store the result of the conversion.

From the datasheet, the minimum required acquisition time is 2.45 μs. This time shows that the ADC requires some time to make sure that the whole conversion process is completed before follow up with another conversion. For a 10-bit device, the minimum step size of the converter is 1/1023.

$$Step\ size = \frac{1}{2^{10} - 1} = \frac{1}{1023}$$

To configure the port pins of the PIC to receive analog signal and convert it into digital form, the registers need to be set in the firmware. Below shows a part of the coding in order to use port A0 and port A1 as the analog input port with ADC on.

```
#define DEMO_BOARD PICDEM_FS_USB
#define PICDEM_FS_USB
#define CLOCK_FREQ 48000000



/** SWITCH *********************************************************/
#define mInitAllSwitches()    TRISBbits.TRISB0=1;
#define button              PORTBbits.RB0


/** POT ************************************************************/

#define mInitPOT1()          {TRISA=0b00000001;ADCON0=0b00000001;ADCON1=0x00;ADCON2=0b10010100;}
#define mInitPOT2()          {TRISA=0b00000010;ADCON0=0b00000101;ADCON1=0x00;ADCON2=0b10010100;}
```

Figure 3.14 Part of the firmware

3.3.1.3 SK40C Development Board

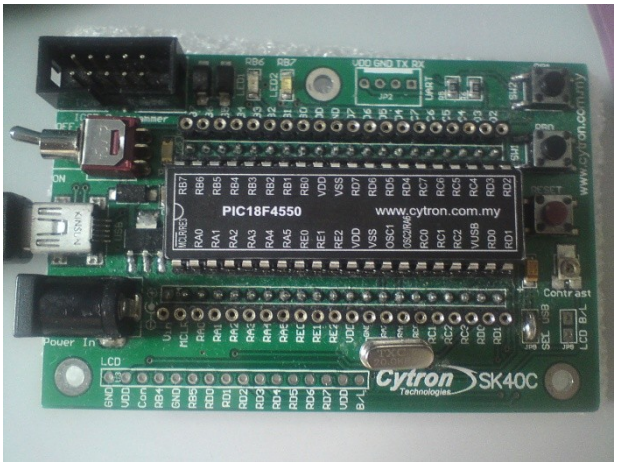

Figure 3.15 SK40C development board

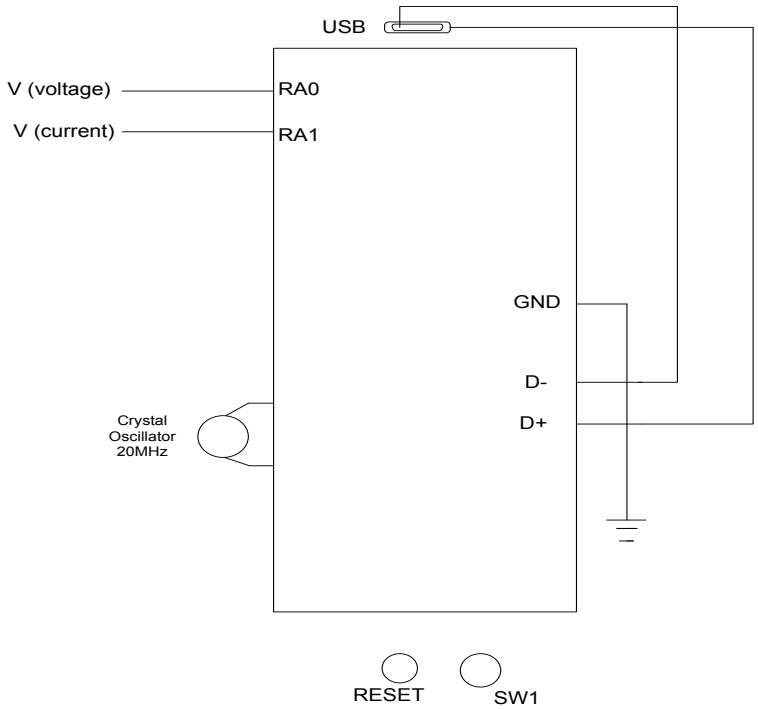

Figure 3.16 Schematic of the connection of SK40C board

The SK40C is a device made by Cytron Technologies to provide the users to speed up the development of a PIC related projects. This board only contains some basic components needed to do programming such as reset button, connector for programmer, power indicator LED, USB connector, programmable push buttons and others. All the interface and program must be written and construct by the users themselves. By using the development board, many soldering work can be eliminated

and users no longer requires to plug-in and out the PIC for programming. All in all, it helps new microcontroller users to develop their project faster and more comfortable.

Figure shows the connection made on the SK40C development board. The output voltages from the rectifiers were fed into port RA0 and RA1. The crystal oscillator is connected on the port OSC1 and OSC2. The USB port is already connected well in the board and hence the port can be plugged in directly using the suitable pair of the USB head.

3.3.1.4 Ports

Figure 3.17 Parallel port

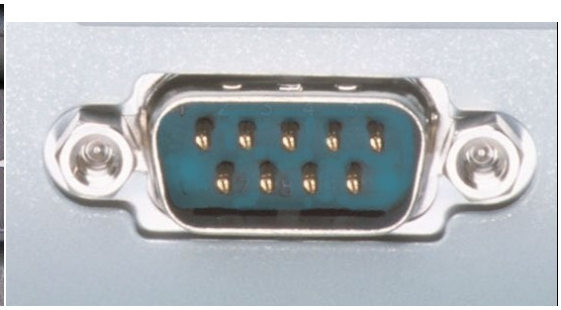

Figure 3.18 Serial port

Figure 3.19 USB port

Ports are use to link the circuitry and the computer system together. They act as the medium for communication link. Ports such as serial and parallel port will be chosen to achieve the purpose mentioned. Serial ports allow information transferring and receiving one bit at a time. Serial port uses RS232 standard as its protocol [8].

On the other hand, parallel interfacing which uses parallel port as communication and transmission link is able to transmit and receive bits of data at the same time. Parallel port also known as printer port and it uses IEEE 1284 standard [9].

USB port is a newer version of the standard port used in a computer. USB ports are smaller and are able to transfer data way much faster than parallel and serial port could. It is also able to supply the required power to the USB devices without needing external supply [10].

i) USB

In today's computers and laptops, USB can be found at any corners of the powerful calculator. Compared to 10 years ago which uses Serial and Parallel ports as the interfacing medium for the external devices, USB is way much faster and smaller. With the continuous development of the USB by many leading companies in computer and electronics, more and more advanced version of USB specification had been released. From the original USB 1.0 specification which carries transfer rate of 1.5 Mbit/s to transfer rate up to 5 Gbit/s in USB 3.0, the speed of the USB is faster day by day. Compared to serial port that has data transfer rate of maximum 115200 bit/s and parallel port of 16Mbit/s, USB is obviously many times faster than these conventional ports. Besides, USB is also smaller and lighter compared to its predecessor and can fit more ports in a single PC. Due to the various reasons above, USB had replaced serial and parallel ports in this modern days where speed and size matters. Therefore, to make sure that this device made can fit all the computers that might be used by the users, USB as the interfacing medium is very important.

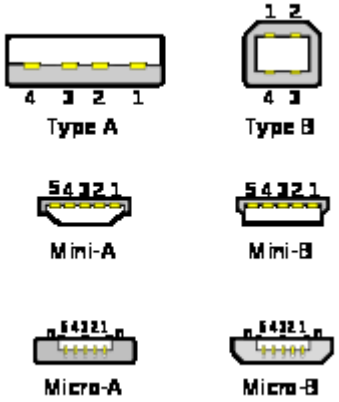

Figure 3.20 Types of USB port

USB comes in many device classes such as Audio, Communication, Printer, Mass Storage, Human Interface Device (HID) and so on. In this project, HID classes had been implemented because HID is much easier to be programmed without having to worried about drivers. All the required drivers had been made inside Windows and we just have to specify the device classes by addressing the appropriate Product ID (PID) and Vendor ID (VID) in the firmware. PID and VID is a 16-bit number which PC used to identify and provide the driver for the USB device.

USB comes in various design including Standard, Mini and Micro USB connector. USB only need +5 V in order to function and hence the power consumption is very small. There are 4 pins in a standard USB while 5 pins in mini and micro types. The data of the pins are shown in table below:

Table 3.2: USB Standard Pinout

PIN	NAME	DESCRIPTION
1	Vbus	+5 V
2	D-	Data -
3	D+	Data +
4	GND	Ground

Table 3.3: USB Mini/Micro Pinouts

PIN	NAME	DESCRIPTION
1	Vbus	+5 V
2	D-	Data -
3	D+	Data +
4	ID	Allow the computer to differenciate between A plug and B plug
5	GND	Ground

3.3.2 Software Part

3.3.2.1 Personal Computer

A computer is a powerful calculator with the ability to process data in a short interval. Nowadays, computer is very important equipment to not only working people but also students. Computer in 21st century has a lot of functions and helps not only in processing data with ease and speed but also support a lot of software. Computer had become a part of our life and developing a device that can communicate with it is a relief to all the users.

3.3.2.2 MPLAB IDE and PICkit2

MPLAB IDE is called an Integrated Development Environment (IDE) as it allows users to develop code for microcontroller in a single software environment. It contains a compiler, software and hardware debugger, editor, project manager, linker and execution engines. This software is developed by Microchip Technology and is used for the programming of the microcontroller [11].

PICkit2 programmer application is also produced by Microchip Technology. It is used for writing the firmware written in MPLAB IDE into the EEPROM and Flash microcontroller [12]. With both the software, it is sufficient to activate most of the microcontroller devices available in the market.

MPLAB IDE uses C language and it is a very fundamental language in programming. By having this PIC programming software, everything the users need in all in one packet. Users can check the memory requirement, stability of the firmware and direct compilation after finished programmed. If there is any error, MPLAB IDE also provides a debugger to trace the bugs in it.

PICkit2 is used to burn the firmware into the microchip. Combined with MPLAB IDE, they can complete the whole microchip programming function in a quick manner.

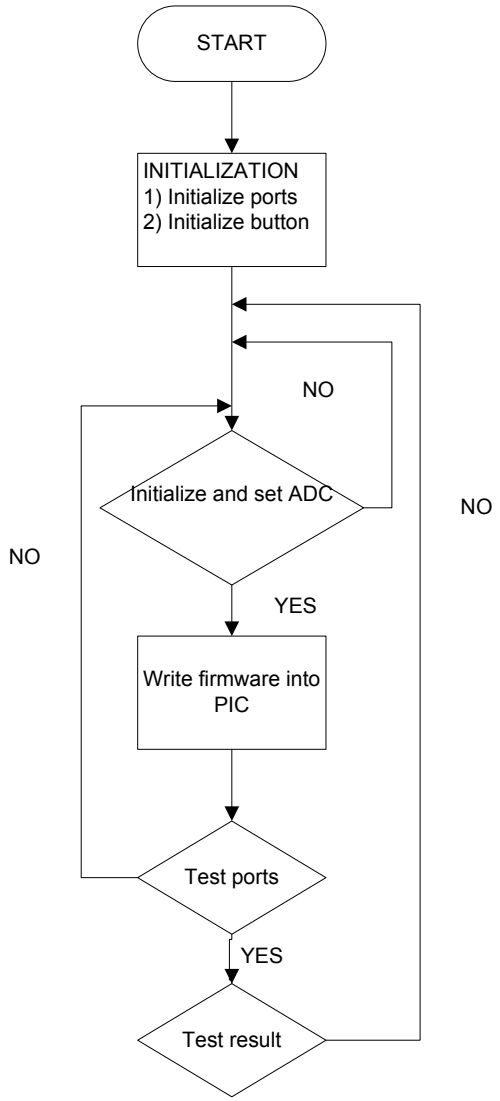

Figure 3.21 Algorithm for programming the firmware of PIC

3.3.2.3 Visual Basic 2008

Figure 3.22 Visual Studio 2008 Logo

Visual Basic 2008 is a programming language in Visual Studio 2008 that allows user to design and create software of his own. Visual basic is a rather easy understandable programming language and operates in Windows. Visual Basic has the advantages in the development of graphical user interface (GUI) comparing to the traditional language such as C, FORTRAN and C++. As the world slowly adopting GUI, Visual Basic is becoming more and more popular among programmers and software developers. GUI provides users an easy to learn and understand interface. Just by looking at the description on a button, the user knows that it can be pressed and will be able to expect what to get when the button is pressed.

With Visual Basic, a nice GUI can be made without needing to write thousands of coding. A simple button can be added to the system by dragging or inserting a button control in Visual Basic interface toolbox but if we wanted to have a button in C, we need to use coding to specified the width, length, texts in the buttons and is very troublesome if we want the software to have a lot of buttons and textboxes.

Other than buttons and textboxes, Visual Basic gives the user a lot of functions that is required in most GUI based development such as checkbox, graphical plot, background editing, drop boxes and so on. All these objects can be add into the software by just a single click and then add some command for the objects to function or respond to events. Hence, Visual Basic provides the user to create an user friendly interface software with greater ease [10].

i) Visual Basic Based Interface Software

After all the hardware and data transferring system had been developed, there must be someone to control all these processes and handle the data transferred. Software based on Visual Basic will be the one who will collect these data

transferred from the hardware as well as indirectly give command to the hardware to start or stop working.

Visual Basic is chosen as the programming language because it is easier to understand and write. This software will detect whether the device is connected or not, then send a signal to start receiving data after the push button on the SK40C board had been pressed. The software will start receiving data from the PIC and then calculations will be done in the software to get the values of voltage, current, power factor and power of the equipment being measured. The profile of all the parameters will also be plotted automatically by the software itself. Users can easily interact with the software through clearly labeled push buttons on the interface of the software.

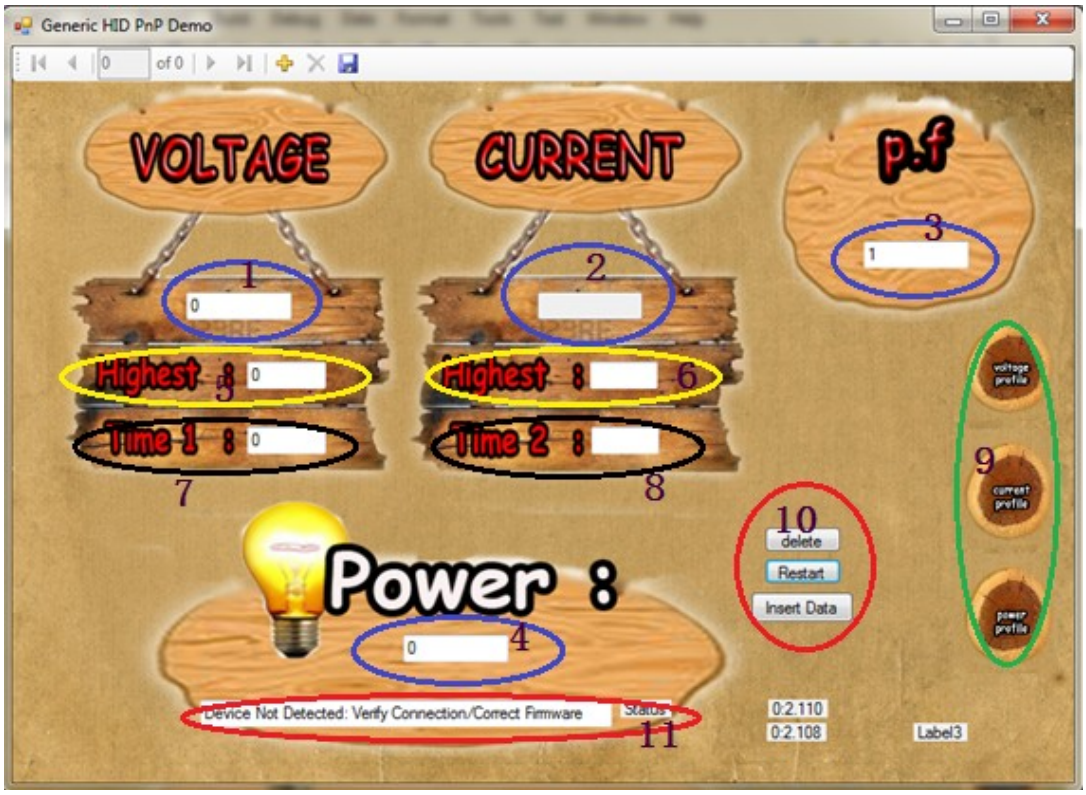

Figure 3.23 The interface of the software

Table 3.4: The description of the software interface

No.	Description
1	Instantaneous voltage
2	Instantaneous current
3	Power factor
4	Average power
5	Highest rms voltage logged
6	Highest rms current logged
7	Time logged when the highest rms voltage occurs
8	Time logged when the highest rms voltage occurs
9	Push buttons to show the profile of voltage, current and power
10	"Insert data" button is used when we want to save the result in database, "delete" button will clear all the database and "Restart" button stop and reset the timer
11	Detect whether the circuit is connected to the USB port of computer

When the system runs, the data from both transducers will be sent to the PIC and then converted into digital form. The digital signals will then be sent to the computer via USB cable and then capture by the software interface. The software will get the data alternately and then calculate and shows in area 1 and 2. As the data keep flowing into the system, the software will continue to capture the values of the instantaneous voltage and current. If the value of instantaneous voltage and current captured is higher than the one captured before, it will be logged into area 5 and 6. The time logged that is area 7 and 8 will be the time obtained when the system gets the highest voltage and current logged in the area 5 and 6. The power factor of the system at area 3 is calculated using the time logged in 5 and 6. The average power at area 4 will then be calculated by the system by using all the parameters above.

The working algorithm of the software is shown below:

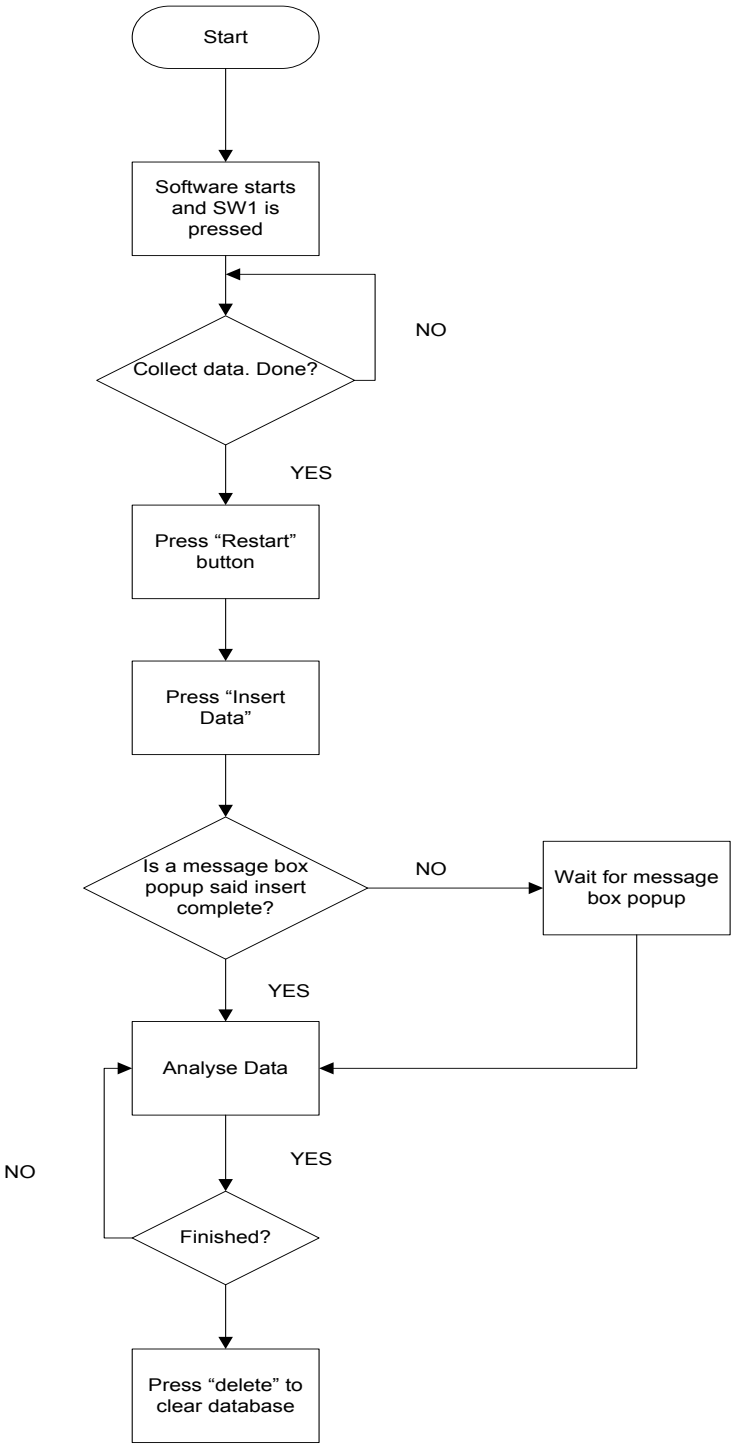

Figure 3.24 Algorithm of software

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this project, a few tests had been done to verify and obtain the results from the system developed. An electric kettle and an electric toaster had been used to test the effectiveness of the device. Firstly, the output voltage and current from the transducers with the electrical appliances connected will be measured and captured by the oscilloscope along with its waveforms. Then the outputs will be run through the bridge rectifier and the results were saved again. Later the whole circuit system will be implemented and the rms voltage, rms current, power factor and average power of the electrical equipment tested were obtained and shown in the interface software. Lastly, a power meter is used to verify the experimental results with the actual values. Analysis is done later on to compare the results and comment on the effectiveness of the system.

4.2 Output from Transducers

Tests had been conducted to make sure that the signal that will flow in the PIC is well under 5 V. This is important as the rated input of the PIC must be less than +5 V or the PIC will burn.

4.2.1 Procedures

1) The circuit was connected as shown in **Figure 3.2**.
2) The power supply for the transducers that is ±15 V is being supplied.
3) The outputs from both the transducers were connected to the oscilloscope.
4) The electric kettle is then connected to the power socket and the power cord which is connected to the power outlet was switched on.
5) The results from the oscilloscope were saved and recorded.
6) The test was then repeated with the electric toaster.

4.2.2 Result

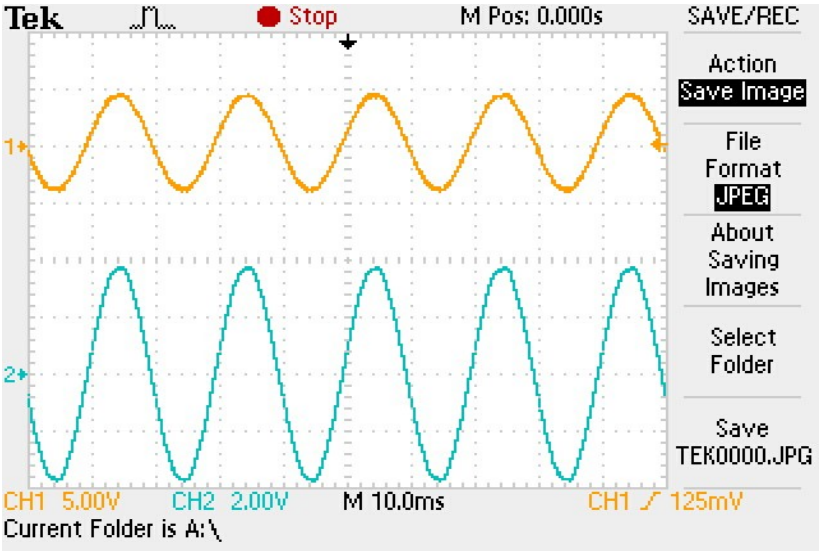

Figure 4.1 Output from oscilloscope 1 (electric kettle)

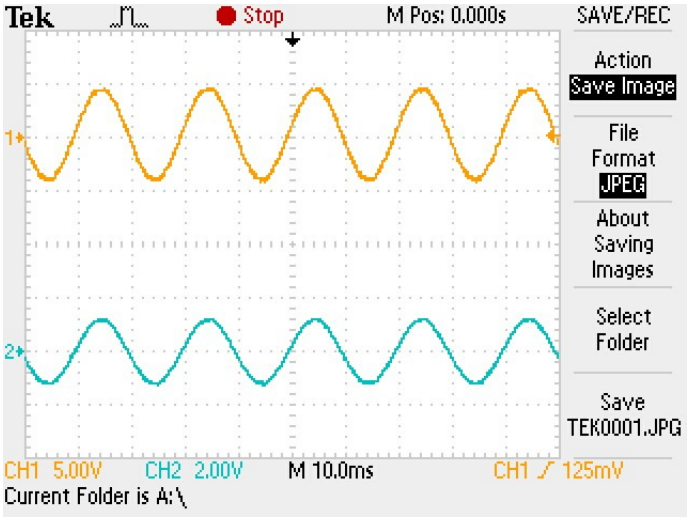

Figure 4.2 Output from oscilloscope 1 (electric toaster)

The result from the tests is shown in the table below:

Table 4.1: Result of first test

ELECTRICAL APPLIANCES	RMS VOLTAGE (VOTAGE)	RMS VOLTAGE (CURRENT)	POWER FACTOR	AVERAGE POWER
Electric Kettle	2.96 V	2.64 V	1.0	2026.02 W
Electric Toaster	2.88 V	0.85 V	1.0	636.48 W

4.3 Output from Transducer through Bridge Rectifier

After the value of voltage and current were reduced into a acceptable range, the outputs from the previous test are passed through the bridge rectifier to filter out the negative values.

4.3.1 Procedures

1) The circuit was connected as shown in **Figure 3.2**.
2) The power supply for the transducers that is ±15 V is being supplied.
3) The outputs from both the transducers were connected to the oscilloscope.
4) The electric kettle is then connected to the power socket and the power cord which is connected to the power outlet was switched on.
5) The results from the oscilloscope were saved and recorded.
6) The test was then repeated with the electric toaster.

4.3.2 Result

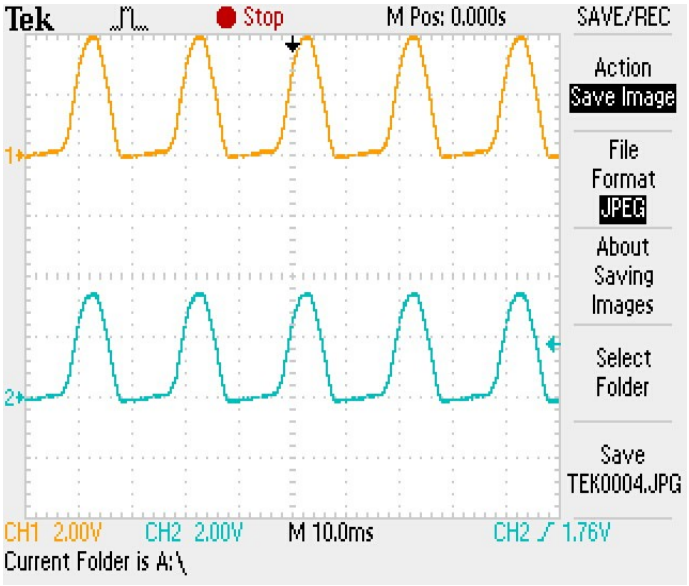

Figure 4.3 Output from oscilloscope 2 (electric kettle)

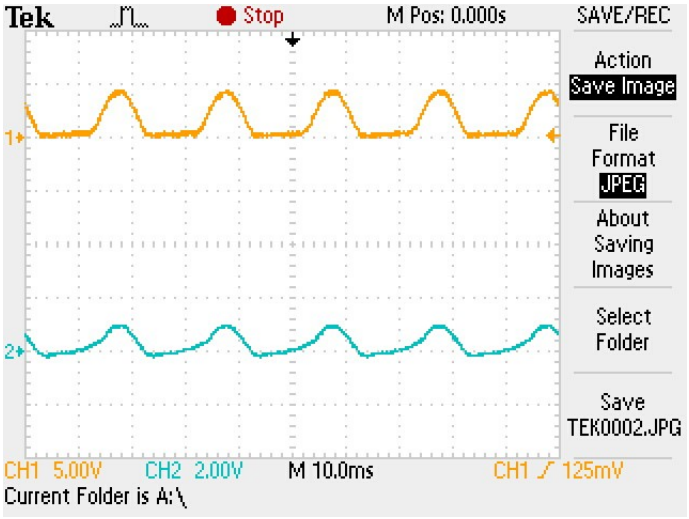

Figure 4.4 Output from oscilloscope 2 (electric toaster)

The results are almost identical to the test shown in the previous test as shown below:

Table 4.2: Result of second test

ELECTRICAL APPLIANCES	RMS VOLTAGE (VOTAGE)	RMS VOLTAGE (CURRENT)	POWER FACTOR	AVERAGE POWER
Electric Kettle	2.93 V	2.61 V	1.0	1988.3 W
Electric Toaster	2.85 V	0.88 V	1.0	652.08 W

4.4 Output of the Whole Circuit System

When all the outputs were tested to be able to fit into microcontroller, the entire circuit system is connected by combining the Hardware Design and Interface Design together.

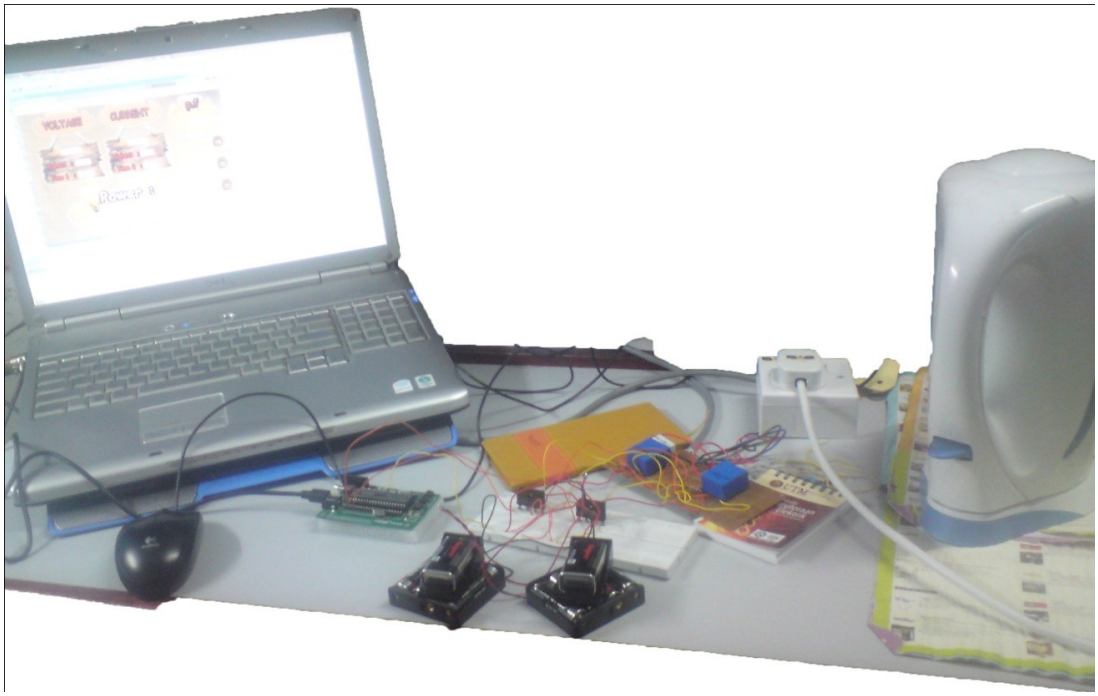

Figure 4.5 The whole system

4.4.1 Procedure

1) The circuit was connected as shown in **Figure 3.2** and **Figure 3.9**.
2) The power supply for the transducers that is ±15 V is being supplied by batteries.
3) The outputs from bridge rectifier were plugged into port A0 and A1 of PIC18F4550 mounted on SK40C board.
4) The USB cable that is connecting the SK40C board was then plugged in into the PC.
5) The electric kettle was also plugged into the power socket and the power plug was switch on after every connection was completed.
6) After the power had been switched on, the interface software was run and the push button on the SK40C board was pushed to start transferring data to PC.
7) Data were collected by the software and then calculated by the program
8) The results were clearly shown in the interface of the software.
9) The test was repeated by replacing the electric kettle with electric toaster.

4.4.2 Result

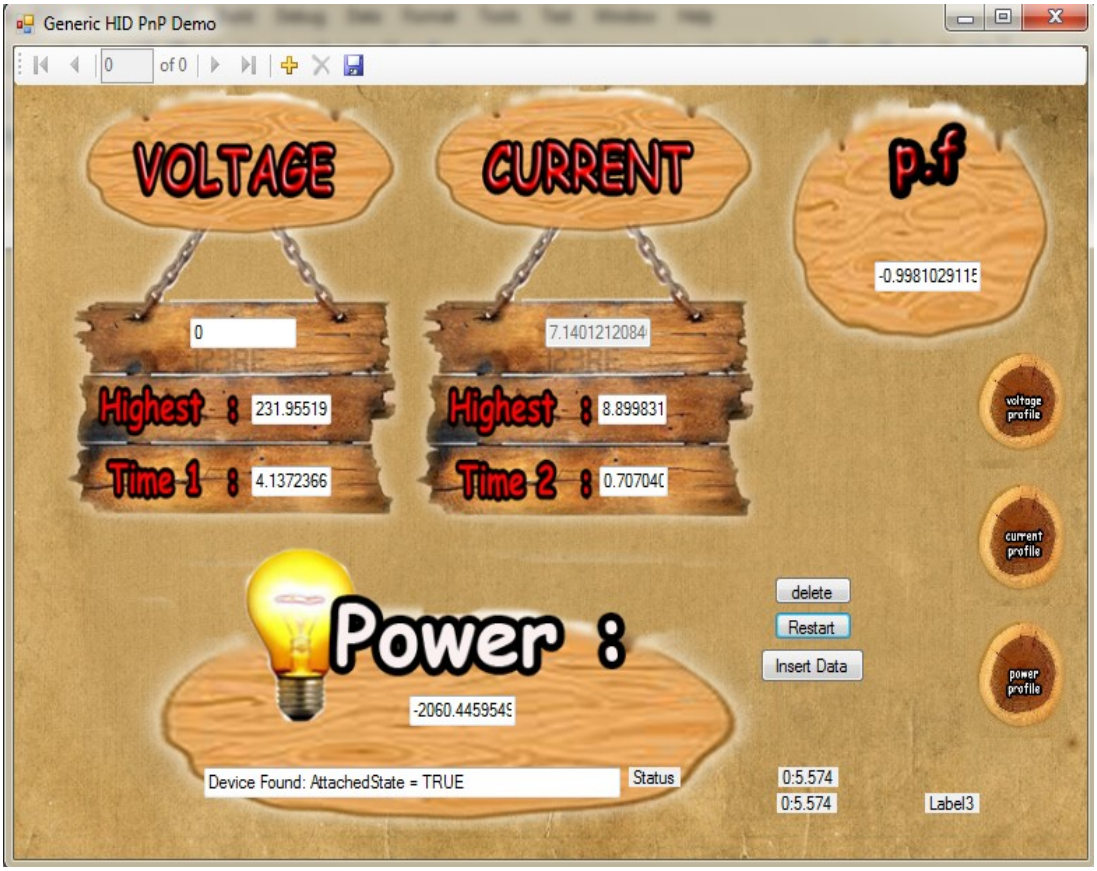

Figure 4.6 The result from the software (electric kettle)

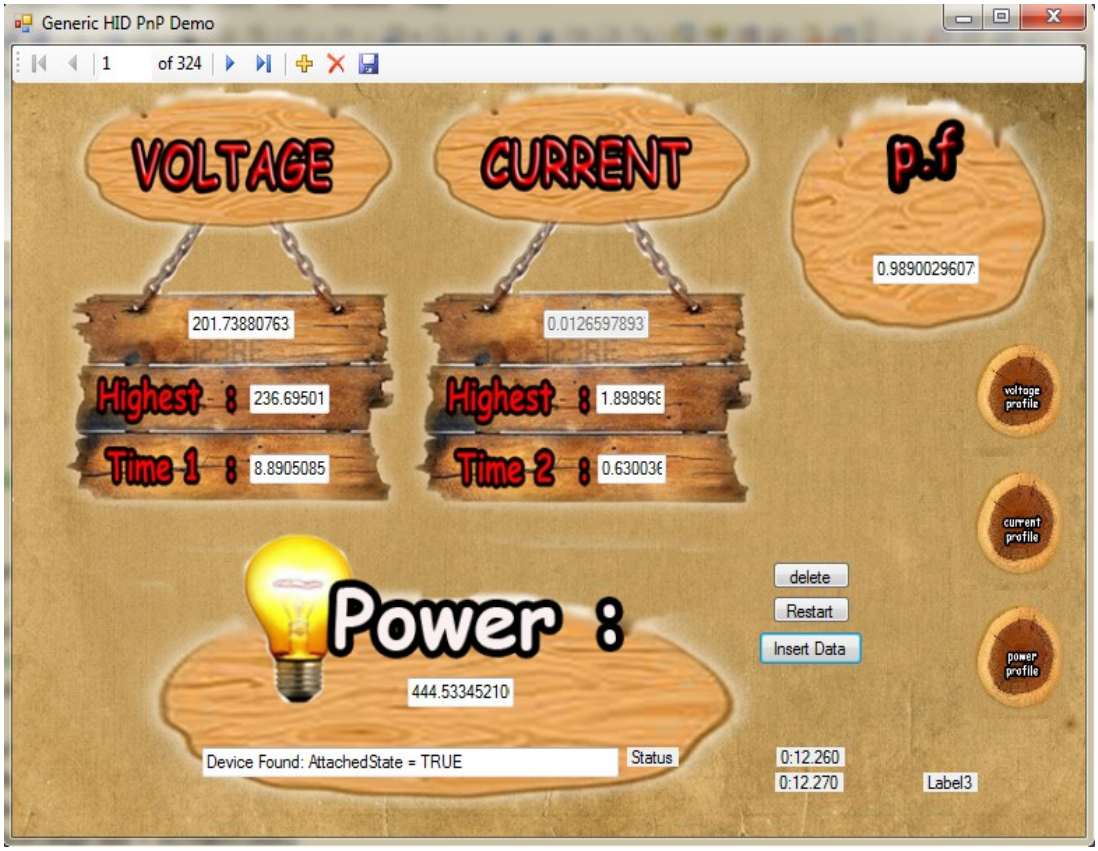

Figure 4.7 The result from the software (electric toaster)

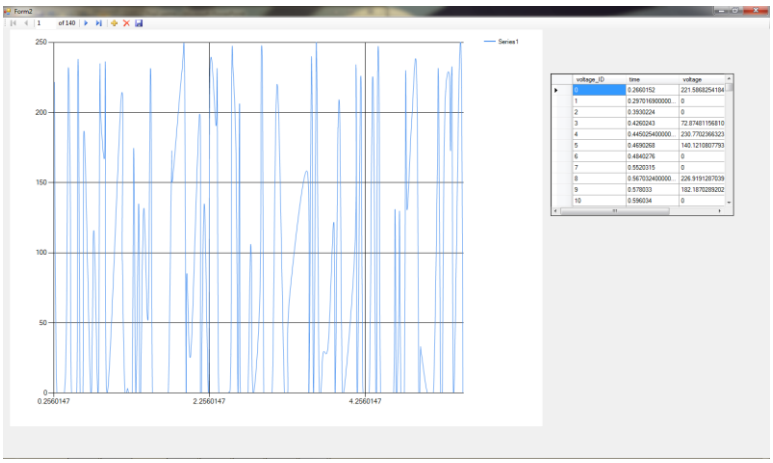

Figure 4.8 Voltage profile (electric kettle)

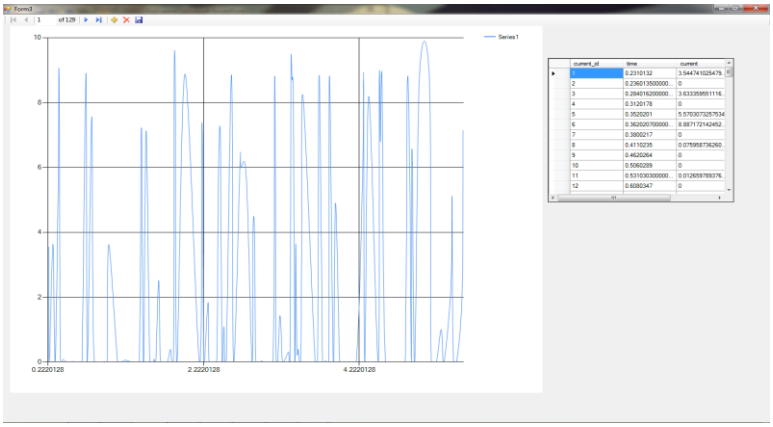

Figure 4.9 Current profile (electric kettle)

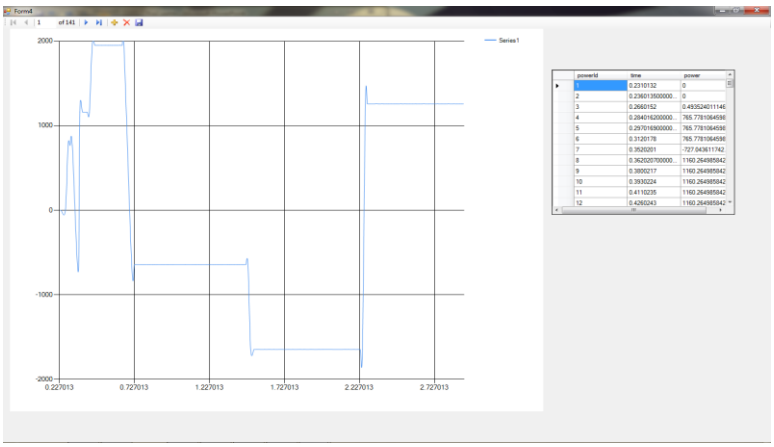

Figure 4.10 Power profile (electric kettle)

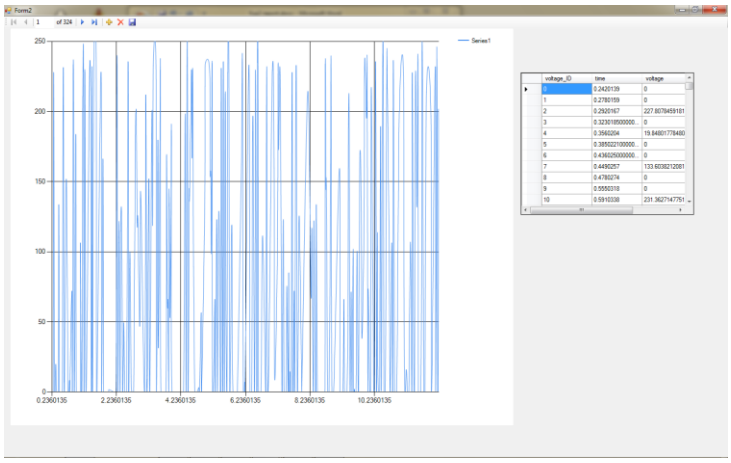

Figure 4.11 Voltage profile (electric toaster)

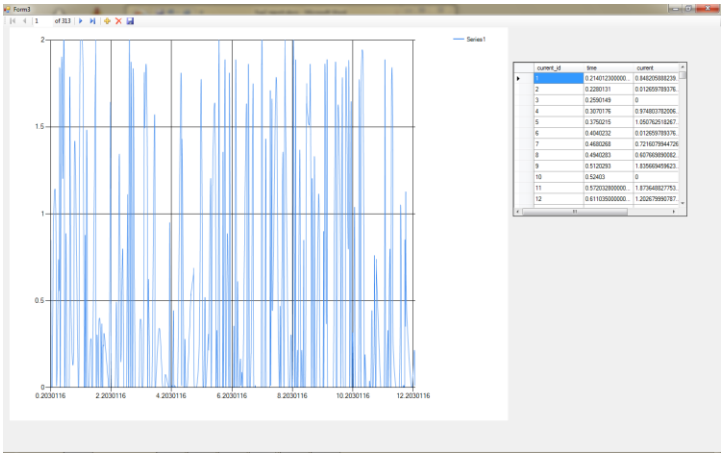

Figure 4.12 Current profile (electric toaster)

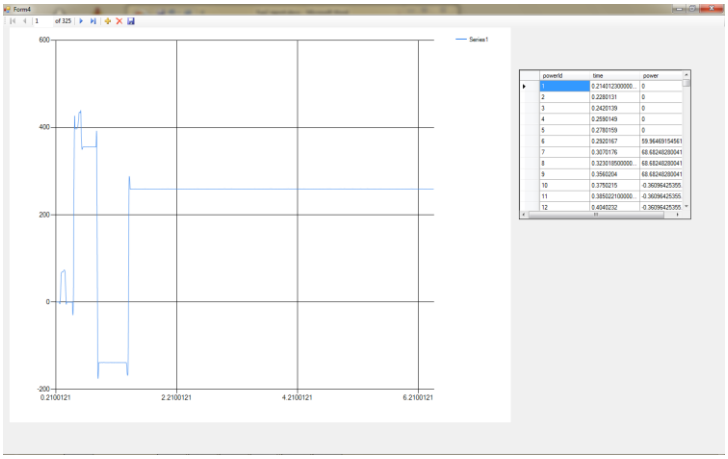

Figure 4.13 Power profile (electric toaster)

Table 4.3: Result of system test

ELECTRICAL APPLIANCES	RMS VOLTAGE	RMS CURRENT	POWER FACTOR	AVERAGE POWER
Electric Kettle	231.96 V	8.9 V	-0.9981	-2060 W
Electric Toaster	236.7	1.9	0.989	444.5

4.5 Result from Power Meter

To verify the result of the circuit system implemented in this project, the power meter was used to measure the actual power of the equipment being measured. The power meter was connected as shown in the schematic below:

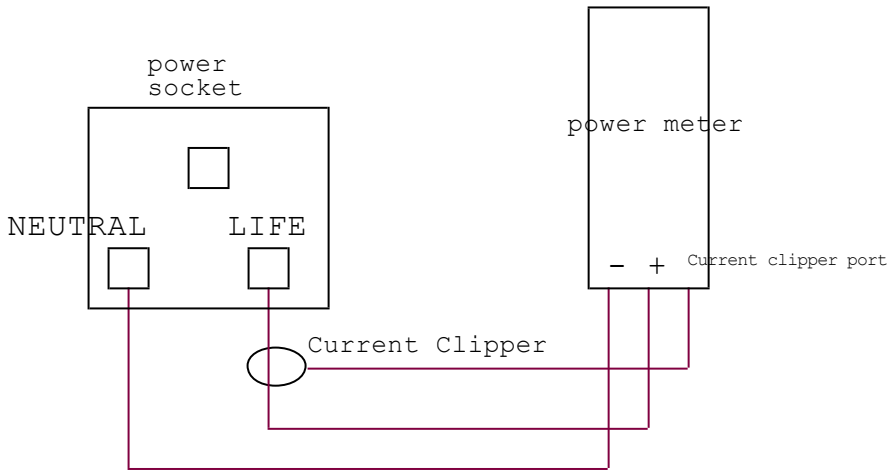

Figure 4.14 Connection of power meter

Figure 4.15 Power meter (kettle)

Figure 4.16 Power meter (toaster)

Table 4.4: Result of power meter

ELECTRICAL APPLIANCES	RMS VOLTAGE	RMS CURRENT	POWER FACTOR	AVERAGE POWER
Electric Kettle	241 V	9.2 V	1.0	2220 W
Electric Toaster	244 V	2.9 V	1.0	709 W

4.6 Discussion

From the first test on the ability of voltage and current transducer, the waveform and values that were obtained are almost as accurate. The output waveforms show the sinusoidal waveform with frequency of 50 Hz and different amplitudes. Hence the test had proven that the transducers successfully convert the high voltage and current from supply in within ±5 V.

In the second phase, the outputs from the transducers were fed into the bridge rectifiers. The result shows that the negative side of the sinusoidal waveform had been successfully filtered out with a small drop in voltages. This happens because the rectifier requires a small forward voltage before it conduct electric.

When the whole system were being ran, output result that is shown gives almost accurate values comparing to the actual values measured by using power meter. There is about 10 % of error when compared with the values obtained from power meter with the one using the circuit system when tested with electric kettle. On the other hand, the test with the electric toaster yielded larger error about 37%. In order to acquire more accurate result, the system needs to find the actual highest rms voltage and current when operating. Because the speed limitation of the system, it needs to operate for a longer time in order to become more accurate.

Also, from the comparison between the different ratings of power of electrical appliances, because the minimum nominal value of current is 5 A, hence the power of the equipment being measured must have at least 1 kW to obtain the best accuracy from the system. The error of the accuracy increases as the value of current of the input decreases. From the case of electric kettle, it clearly shows that the current of the input will heavily affect the accuracy of the system. From calculations, the nominal value of the input current of the electric toaster should be around 3 A and this value is well below the rating of the nominal current and hence the accuracy suffers.

Regarding the power factor of the system, because the time used to calculate the power factor is depending on the ability of system to obtain the highest rms values of both the voltage and current, hence it will take time for the power factor to be stable and accurate too.

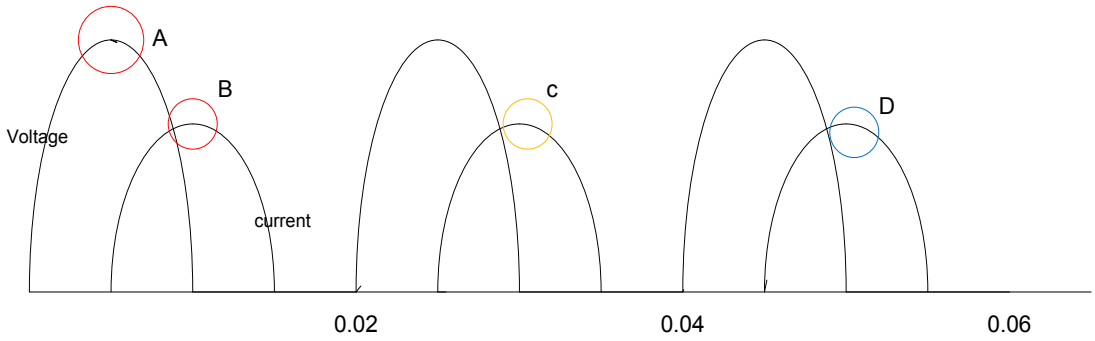

Figure 4.17 Calculation of power factor

Let say if the peak voltage occurs at point A at 0.005 sec and the peak current occurs at point B at 0.006 sec. The power factor will be:

$$PF = \cos\left(\frac{Time\ voltage\ peak - Time\ current\ peak}{0.02} \times 360°\right)$$

$$= \cos\left(\frac{0.005 - 0.006}{0.02} \times 360°\right) = 0.9511$$

But because the system cannot capture the peak current at a short interval after it capture the peak voltage, hence it might capture the peak current at another cycle. Then we do the calculations when the time captured at point C or at point D where the current is at peak value at time 0.026 sec and 0.046 sec respectively while the time of the peak voltage is maintain at 0.005 sec.

$$PF = \cos\left(\frac{Time\ voltage\ peak - Time\ current\ peak}{0.02} \times 360°\right)$$

$$= \cos\left(\frac{0.005 - 0.026}{0.02} \times 360°\right) = \cos\left(\frac{0.005 - 0.046}{0.02} \times 360°\right)$$

$$= 0.9511$$

It is found out that the power factor remains the same because from the trigonometrical identities,

$$\cos(\theta + 2\pi) = +\cos\theta$$

Hence the concept used in the calculation of power factor is correct.

Besides that, the voltage, current and power profile were shown when the buttons on the software interface. The graph of voltage, current, and power against time were plotted.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, power measurement is used not only in industry and research area but also slowly adapt in domestic houses. One will be able to know how much the total power consumed daily and can plan their use of each electrical appliance. As for the research group, they can store the data collected with ease and read them anytime they want. Analysis on the power profile can be made easily using the user friendly software interface. The industry can also use the power measurement tools to identify the machine that consume the most reactive power and probably can increase the power factor of the machine or factory by changing or installing capacitors.

By using basic components such as transducers and microcontroller, the data acquisition system can be easily developed and used in the measurement of power and profile of the electrical equipment. The voltage, current and power factor can be measured easily and stored in any computer with the software installed in it. Whether it is a home desktop PC or laptop to a netbook, each and every computer now have at least 2 USB ports. This means that the portability of this device is very high and can be used almost everywhere without constrain from computer hardware.

In most power meter or wattmeter, although it is can be handheld and portable, but they lack data storing ability of this device developed. Some of the available power meters are able to plot graph on the LCD screen, however, to save it

remains a problem for them. This device solves all the weakness of the currently available power measurement devices and contains almost as strong measuring power as them.

The software developed used to calculate and store data using GUI from Visual Basic Language is very easy to be used. Everything they can see on the interface is clearly shown and can be use directly. Long manual books or training is not required when using the software and the device. Hence it is user-friendly and acceptable even to someone with little knowledge about electronics and electric. All they need is just to know how to read and understand the description on the interface.

In overall, most of the objectives had been successfully achieved. The accuracy and the speed of the system to obtain data is the only concern in this project. This might be due to the programming software used is slower and affect the ability of the data acquisition process.

5.2 Recommendation

In this project, the speed of the system is an important criterion in the system. The accuracy of the system to measure the power and power factor depend heavily on the speed of the data logged in the software. This is because to obtain power in the system, the calculations of peak voltage and current are needed and these parameters have to be as close to actual peak values as possible. This means that the system needs to get more data in a cycle so that the peak current and voltage can be obtained more easily and increase the efficiency and accuracy of the system. Regarding the power factor, the method used is also relies on the accuracy of how fast the system finds the highest voltage and current. Power factor calculation can differ much even the error of the system is low. This is because the frequency of the system is 50 Hz and hence in one cycle, the time is only 0.02 s. Difference in 0.01 s will cause 50% of error in the system and that is why the speed of the system to acquire data utmost important.

In order to make the system more stable and accurate, the speed of the system to obtain data from must be increased. To improve the speed of the system, a faster programming language such as C or C++ can be used so that the running of the code in the software is faster and hence the speed of the system.

Besides that, an external memory can also be used as the temporary storage for the system to store the data from the PIC first. After all the data had been collected in the external memory, the data will only be sent to the PC using USB to reduce the time to transfer and process data.

Other than that, another method such as Zero Crossing to calculate the power factor can also be used so that the phase difference between voltage and current can be easily found. This is because the method used in this project is to find the highest point in the sinusoidal waveform of voltage and current. This method can be hard to obtain the accurate highest point especially there is a short time interval between the acquisitions of 2 data.

Also, another PIC which contains a higher bit of ADC can be used to improve the step size to reduce error in the system. Two PIC or PIC with two ADC can also improve the speed of the system. This is because in this project, only one ADC is available in the PIC and there are 2 parameters that is needed to collect at a time. Therefore the ADC had to switch from one parameter to another to be converted into digital signal and this had wasted 50% of the time if 2 ADCs were available.

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APPENDIX A

PIC18F4550 Datasheet

MICROCHIP

PIC18F2455/2550/4455/4550

28/40/44-Pin, High-Performance, Enhanced Flash, USB Microcontrollers with nanoWatt Technology

Universal Serial Bus Features:

- USB V2.0 Compliant
- Low Speed (1.5 Mb/s) and Full Speed (12 Mb/s)
- Supports Control, Interrupt, Isochronous and Bulk Transfers
- Supports up to 32 Endpoints (16 bidirectional)
- 1 Kbyte Dual Access RAM for USB
- On-Chip USB Transceiver with On-Chip Voltage Regulator
- Interface for Off-Chip USB Transceiver
- Streaming Parallel Port (SPP) for USB streaming transfers (40/44-pin devices only)

Power-Managed Modes:

- Run: CPU on, Peripherals on
- Idle: CPU off, Peripherals on
- Sleep: CPU off, Peripherals off
- Idle mode Currents Down to 5.8 μA Typical
- Sleep mode Currents Down to 0.1 μA Typical
- Timer1 Oscillator: 1.1 μA Typical, 32 kHz, 2V
- Watchdog Timer: 2.1 μA Typical
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, including High-Precision PLL for USB
- Two External Clock modes, Up to 48 MHz
- Internal Oscillator Block:
  - 8 user-selectable frequencies, from 31 kHz to 8 MHz
  - User-tunable to compensate for frequency drift
- Secondary Oscillator using Timer1 @ 32 kHz
- Dual Oscillator Options allow Microcontroller and USB module to Run at Different Clock Speeds
- Fail-Safe Clock Monitor:
  - Allows for safe shutdown if any clock stops

Peripheral Highlights:

- High-Current Sink/Source: 25 mA/25 mA
- Three External Interrupts
- Four Timer modules (Timer0 to Timer3)
- Up to 2 Capture/Compare/PWM (CCP) modules:
  - Capture is 16-bit, max. resolution 5.2 ns (TCY/16)
  - Compare is 16-bit, max. resolution 83.3 ns (TCY)
  - PWM output: PWM resolution is 1 to 10-bit
- Enhanced Capture/Compare/PWM (ECCP) module:
  - Multiple output modes
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart
- Enhanced USART module:
  - LIN bus support
- Master Synchronous Serial Port (MSSP) module Supporting 3-Wire SPI (all 4 modes) and I²C™ Master and Slave modes
- 10-Bit, Up to 13-Channel Analog-to-Digital Converter (A/D) module with Programmable Acquisition Time
- Dual Analog Comparators with Input Multiplexing

Special Microcontroller Features:

- C Compiler Optimized Architecture with Optional Extended Instruction Set
- 100,000 Erase/Write Cycle Enhanced Flash Program Memory Typical
- 1,000,000 Erase/Write Cycle Data EEPROM Memory Typical
- Flash/Data EEPROM Retention: > 40 Years
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 41 ms to 131s
- Programmable Code Protection
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via Two Pins
- In-Circuit Debug (ICD) via Two Pins
- Optional Dedicated ICD/ICSP Port (44-pin, TQFP package only)
- Wide Operating Voltage Range (2.0V to 5.5V)

Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ECCP (PWM)	SPP	MSSP		EUSART	Comparators	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)					SPI	Master I²C™			
PIC18F2455	24K	12288	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F2550	32K	16384	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F4455	24K	12288	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3
PIC18F4550	32K	16384	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3

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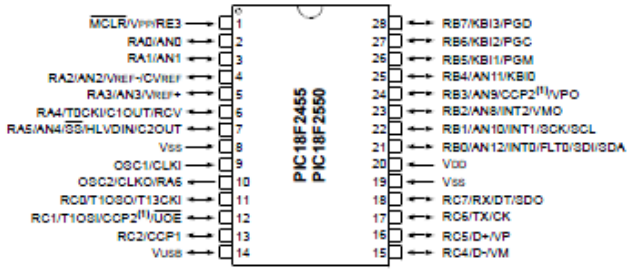
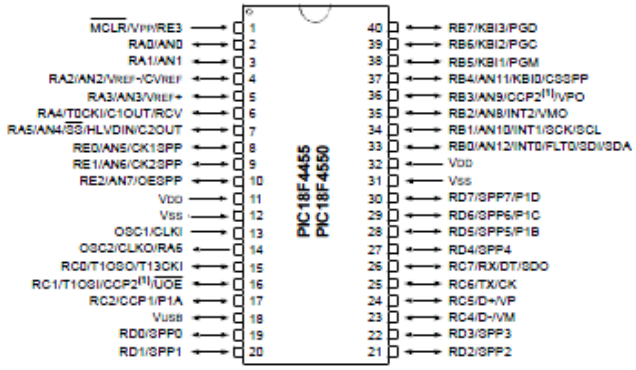
Pin Diagrams

28-Pin PDIP, SOIC



40-Pin PDIP



Note 1: RB3 is the alternate pin for CCP2 multiplexing.

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TABLE 1-2: PIC18F2455/2550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number	Pin Type	Buffer Type	Description
	PDIP, SOIC			
				PORTA is a bidirectional I/O port.
RA0/AN0	2			
RA0		I/O	TTL	Digital I/O.
AN0		I	Analog	Analog input 0.
RA1/AN1	3			
RA1		I/O	TTL	Digital I/O.
AN1		I	Analog	Analog input 1.
RA2/AN2/VREF-/CVREF	4			
RA2		I/O	TTL	Digital I/O.
AN2		I	Analog	Analog input 2.
VREF-		I	Analog	A/D reference voltage (low) input.
CVREF		O	Analog	Analog comparator reference output.
RA3/AN3/VREF+	5			
RA3		I/O	TTL	Digital I/O.
AN3		I	Analog	Analog input 3.
VREF+		I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/C1OUT/RCV	6			
RA4		I/O	ST	Digital I/O.
T0CKI		I	ST	Timer0 external clock input.
C1OUT		O	—	Comparator 1 output.
RCV		I	TTL	External USB transceiver RCV input.
RA5/AN4/$\overline{SS}$/ HLVDIN/C2OUT	7			
RA5		I/O	TTL	Digital I/O.
AN4		I	Analog	Analog input 4.
$\overline{SS}$		I	TTL	SPI slave select input.
HLVDIN		I	Analog	High/Low-Voltage Detect input.
C2OUT		O	—	Comparator 2 output.
RA6	—	—	—	See the OSC2/CLKO/RA6 pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

10.0 I/O PORTS

Depending on the device selected and features enabled, there are up to five ports available. Some pins of the I/O ports are multiplexed with an alternate function from the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin.

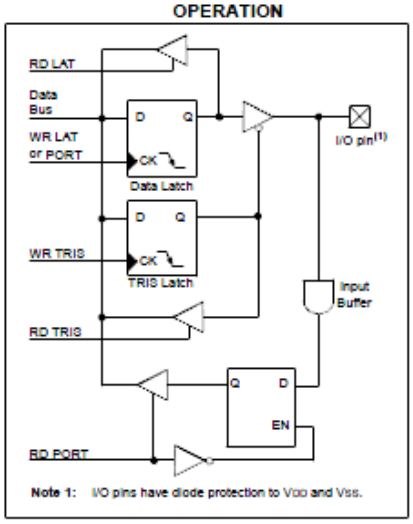
Each port has three registers for its operation. These registers are:

- TRIS register (data direction register)
- PORT register (reads the levels on the pins of the device)
- LAT register (output latch)

The Data Latch register (LATA) is useful for read-modify-write operations on the value driven by the I/O pins.

A simplified model of a generic I/O port, without the interfaces to other peripherals, is shown in Figure 10-1.

FIGURE 10-1: GENERIC I/O PORT OPERATION



Note 1: I/O pins have diode protection to VDD and VSS.

10.1 PORTA, TRISA and LATA Registers

PORTA is an 8-bit wide, bidirectional port. The corresponding Data Direction register is TRISA. Setting a TRISA bit (= 1) will make the corresponding PORTA pin an input (i.e., put the corresponding output driver in a high-impedance mode). Clearing a TRISA bit (= 0) will make the corresponding PORTA pin an output (i.e., put the contents of the output latch on the selected pin).

Reading the PORTA register reads the status of the pins; writing to it will write to the port latch.

The Data Latch register (LATA) is also memory mapped. Read-modify-write operations on the LATA register read and write the latched output value for PORTA.

The RA4 pin is multiplexed with the Timer0 module clock input to become the RA4/T0CKI pin. The RA6 pin is multiplexed with the main oscillator pin; it is enabled as an oscillator or I/O pin by the selection of the main oscillator in Configuration Register 1H (see **Section 25.1 "Configuration Bits"** for details). When not used as a port pin, RA6 and its associated TRIS and LAT bits are read as '0'.

RA4 is also multiplexed with the USB module; it serves as a receiver input from an external USB transceiver. For details on configuration of the USB module, see **Section 17.2 "USB Status and Control"**.

Several PORTA pins are multiplexed with analog inputs, the analog VREF+ and VREF- inputs and the comparator voltage reference output. The operation of pins RA5 and RA3:RA0 as A/D converter inputs is selected by clearing/setting the control bits in the ADCON1 register (A/D Control Register 1).

Note:	On a Power-on Reset, RA5 and RA3:RA0 are configured as analog inputs and read as '0'. RA4 is configured as a digital input.

All other PORTA pins have TTL input levels and full CMOS output drivers.

The TRISA register controls the direction of the RA pins, even when they are being used as analog inputs. The user must ensure the bits in the TRISA register are maintained set when using them as analog inputs.

EXAMPLE 10-1: INITIALIZING PORTA

```
CLRF    PORTA   ; Initialize PORTA by
                ; clearing output
                ; data latches
CLRF    LATA    ; Alternate method
                ; to clear output
                ; data latches
MOVLW   0Fh     ; Configure A/D
MOVWF   ADCON1  ; for digital inputs
MOVLW   07h     ; Configure comparators
MOVWF   CMCON   ; for digital input
MOVLW   0CFh    ; Value used to
                ; initialize data
                ; direction
MOVWF   TRISA   ; Set RA<3:0> as inputs
                ; RA<5:4> as outputs
```

17.0 UNIVERSAL SERIAL BUS (USB)

This section describes the details of the USB peripheral. Because of the very specific nature of the module, knowledge of USB is expected. Some high-level USB information is provided in **Section 17.10 "Overview of USB"** only for application design reference. Designers are encouraged to refer to the official specification published by the USB Implementers Forum (USB-IF) for the latest information. USB specification Revision 2.0 is the most current specification at the time of publication of this document.

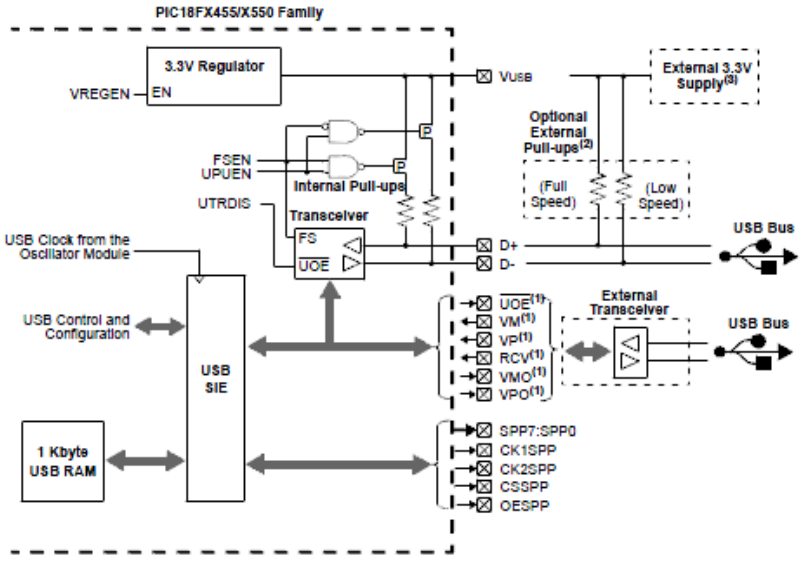
17.1 Overview of the USB Peripheral

The PIC18FX455/X550 device family contains a full-speed and low-speed compatible USB Serial Interface Engine (SIE) that allows fast communication between any USB host and the PIC® microcontroller. The SIE can be interfaced directly to the USB, utilizing the internal transceiver, or it can be connected through an external transceiver. An internal 3.3V regulator is also available to power the internal transceiver in 5V applications.

Some special hardware features have been included to improve performance. Dual port memory in the device's data memory space (USB RAM) has been supplied to share direct memory access between the microcontroller core and the SIE. Buffer descriptors are also provided, allowing users to freely program endpoint memory usage within the USB RAM space. A Streaming Parallel Port has been provided to support the uninterrupted transfer of large volumes of data, such as isochronous data, to external memory buffers.

Figure 17-1 presents a general overview of the USB peripheral and its features.

FIGURE 17-1: USB PERIPHERAL AND OPTIONS



Note 1: This signal is only available if the internal transceiver is disabled (UTRDIS = 1).
2: The internal pull-up resistors should be disabled (UPUEN = 0) if external pull-up resistors are used.
3: Do not enable the internal regulator when using an external 3.3V supply.

21.0 10-BIT ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) converter module has 10 inputs for the 28-pin devices and 13 for the 40/44-pin devices. This module allows conversion of an analog input signal to a corresponding 10-bit digital number.

The module has five registers:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)
- A/D Control Register 2 (ADCON2)

The ADCON0 register, shown in Register 21-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 21-2, configures the functions of the port pins. The ADCON2 register, shown in Register 21-3, configures the A/D clock source, programmed acquisition time and justification.

REGISTER 21-1: ADCON0: A/D CONTROL REGISTER 0

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	CHS3	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	ADON
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 7-6 **Unimplemented:** Read as '0'

bit 5-2 **CHS3:CHS0:** Analog Channel Select bits
0000 = Channel 0 (AN0)
0001 = Channel 1 (AN1)
0010 = Channel 2 (AN2)
0011 = Channel 3 (AN3)
0100 = Channel 4 (AN4)
0101 = Channel 5 (AN5)(1,2)
0110 = Channel 6 (AN6)(1,2)
0111 = Channel 7 (AN7)(1,2)
1000 = Channel 8 (AN8)
1001 = Channel 9 (AN9)
1010 = Channel 10 (AN10)
1011 = Channel 11 (AN11)
1100 = Channel 12 (AN12)
1101 = Unimplemented(2)
1110 = Unimplemented(2)
1111 = Unimplemented(2)

bit 1 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit
When ADON = 1:
1 = A/D conversion in progress
0 = A/D Idle

bit 0 **ADON:** A/D On bit
1 = A/D converter module is enabled
0 = A/D converter module is disabled

Note 1: These channels are not implemented on 28-pin devices.
2: Performing a conversion on unimplemented channels will return a floating input measurement.

REGISTER 21-2: ADCON1: A/D CONTROL REGISTER 1

U-0	U-0	R/W-0	R/W-0	R/W-0(1)	R/W(1)	R/W(1)	R/W(1)
—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 7-6 **Unimplemented:** Read as '0'

bit 5 **VCFG1:** Voltage Reference Configuration bit (V_{REF-} source)
1 = V_{REF-} (AN2)
0 = V_{SS}

bit 4 **VCFG0:** Voltage Reference Configuration bit (V_{REF+} source)
1 = V_{REF+} (AN3)
0 = V_{DD}

bit 3-0 **PCFG3:PCFG0:** A/D Port Configuration Control bits:

PCFG3: PCFG0	AN12	AN11	AN10	AN9	AN8	AN7(2)	AN6(2)	AN5(2)	AN4	AN3	AN2	AN1	AN0
0000(1)	A	A	A	A	A	A	A	A	A	A	A	A	A
0001	A	A	A	A	A	A	A	A	A	A	A	A	A
0010	A	A	A	A	A	A	A	A	A	A	A	A	A
0011	D	A	A	A	A	A	A	A	A	A	A	A	A
0100	D	D	A	A	A	A	A	A	A	A	A	A	A
0101	D	D	D	A	A	A	A	A	A	A	A	A	A
0110	D	D	D	D	A	A	A	A	A	A	A	A	A
0111(1)	D	D	D	D	D	A	A	A	A	A	A	A	A
1000	D	D	D	D	D	D	A	A	A	A	A	A	A
1001	D	D	D	D	D	D	D	A	A	A	A	A	A
1010	D	D	D	D	D	D	D	D	A	A	A	A	A
1011	D	D	D	D	D	D	D	D	D	A	A	A	A
1100	D	D	D	D	D	D	D	D	D	D	A	A	A
1101	D	D	D	D	D	D	D	D	D	D	D	A	A
1110	D	D	D	D	D	D	D	D	D	D	D	D	A
1111	D	D	D	D	D	D	D	D	D	D	D	D	D

A = Analog input D = Digital I/O

Note 1: The POR value of the PCFG bits depends on the value of the PBADEN Configuration bit. When PBADEN = 1, PCFG<3:0> = 0000; when PBADEN = 0, PCFG<3:0> = 0111.
2: AN5 through AN7 are available only on 40/44-pin devices.

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REGISTER 21-3: ADCON2: A/D CONTROL REGISTER 2

R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	—	ACQT2	ACQT1	ACQT0	ADCS2	ADCS1	ADCS0
bit 7							bit 0

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

bit 7 **ADFM:** A/D Result Format Select bit
1 = Right justified
0 = Left justified

bit 6 **Unimplemented:** Read as '0'

bit 5-3 **ACQT2:ACQT0:** A/D Acquisition Time Select bits
111 = 20 TAD
110 = 16 TAD
101 = 12 TAD
100 = 8 TAD
011 = 6 TAD
010 = 4 TAD
001 = 2 TAD
000 = 0 TAD(1)

bit 2-0 **ADCS2:ADCS0:** A/D Conversion Clock Select bits
111 = FRC (clock derived from A/D RC oscillator)(1)
110 = FOSC/64
101 = FOSC/16
100 = FOSC/4
011 = FRC (clock derived from A/D RC oscillator)(1)
010 = FOSC/32
001 = FOSC/8
000 = FOSC/2

Note 1: If the A/D FRC clock source is selected, a delay of one TCY (instruction cycle) is added before the A/D clock starts. This allows the SLEEP instruction to be executed before starting a conversion.

21.1 A/D Acquisition Requirements

For the A/D converter to meet its specified accuracy, the charge holding capacitor (C_{HOLD}) must be allowed to fully charge to the input channel voltage level. The analog input model is shown in Figure 21-3. The source impedance (R_S) and the internal sampling switch (R_{SS}) impedance directly affect the time required to charge the capacitor C_{HOLD}. The sampling switch (R_{SS}) impedance varies over the device voltage (V_{DD}). The source impedance affects the offset voltage at the analog input (due to pin leakage current). **The maximum recommended impedance for analog sources is 2.5 kΩ.** After the analog input channel is selected (changed), the channel must be sampled for at least the minimum acquisition time before starting a conversion.

Note: When the conversion is started, the holding capacitor is disconnected from the input pin.

To calculate the minimum acquisition time, Equation 21-1 may be used. This equation assumes that 1/2 LSb error is used (1024 steps for the A/D). The 1/2 LSb error is the maximum error allowed for the A/D to meet its specified resolution.

Example 21-3 shows the calculation of the minimum required acquisition time T_{ACQ}. This calculation is based on the following application system assumptions:

C_{HOLD}	=	25 pF
Rs	=	2.5 kΩ
Conversion Error	≤	1/2 LSb
V_{DD}	=	5V → R_{SS} = 2 kΩ
Temperature	=	85°C (system max.)

EQUATION 21-1: ACQUISITION TIME

$$T_{ACQ} = \text{Amplifier Settling Time} + \text{Holding Capacitor Charging Time} + \text{Temperature Coefficient}$$
$$= T_{AMP} + T_C + T_{COFF}$$

EQUATION 21-2: A/D MINIMUM CHARGING TIME

$$V_{HOLD} = (V_{REF} - (V_{REF}/2048)) \cdot (1 - e^{(-T_C/C_{HOLD}(R_{IC} + R_{SS} + R_S))})$$
or
$$T_C = -(C_{HOLD})(R_{IC} + R_{SS} + R_S) \ln(1/2048)$$

EQUATION 21-3: CALCULATING THE MINIMUM REQUIRED ACQUISITION TIME

$T_{ACQ} = T_{AMP} + T_C + T_{COFF}$

$T_{AMP} = 0.2\ \mu s$

$T_{COFF} = (\text{Temp} - 25°C)(0.02\ \mu s/°C)$
$(85°C - 25°C)(0.02\ \mu s/°C)$
$1.2\ \mu s$

Temperature coefficient is only required for temperatures > 25°C. Below 25°C, $T_{COFF} = 0\ \mu s$.

$T_C = -(C_{HOLD})(R_{IC} + R_{SS} + R_S) \ln(1/2048)\ \mu s$
$-(25\ pF)\ (1\ k\Omega + 2\ k\Omega + 2.5\ k\Omega) \ln(0.0004883)\ \mu s$
$1.05\ \mu s$

$T_{ACQ} = 0.2\ \mu s + 1.05\ \mu s + 1.2\ \mu s$
$2.45\ \mu s$

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APPENDIX B

LV 25-P Voltage Transducer Datasheet

LEM

Voltage Transducer LV 25-P

For the electronic measurement of voltages : DC, AC, pulsed..., with a galvanic isolation between the primary circuit (high voltage) and the secondary circuit (electronic circuit).

I_{PN} = 10 mA
V_{PN} = 10..500 V

16084

Electrical data

I_{PN}	Primary nominal current rms		10		mA
I_{PM}	Primary current, measuring range		0 .. ± 14		mA
R_M	Measuring resistance		$R_{M\,min}$	$R_{M\,max}$	
	with ± 12 V	@ ± 10 mA $_{max}$	30	190	Ω
		@ ± 14 mA $_{max}$	30	100	Ω
	with ± 15 V	@ ± 10 mA $_{max}$	100	350	Ω
		@ ± 14 mA $_{max}$	100	190	Ω
I_{SN}	Secondary nominal current rms		25		mA
K_N	Conversion ratio		2500 : 1000		
V_C	Supply voltage (± 5 %)		± 12 .. 15		V
I_C	Current consumption		10 @ ± 15 V) + I_S		mA

Accuracy - Dynamic performance data

X_G	Overall Accuracy @ I_{PN}, T_A = 25°C	@ ± 12 .. 15 V	± 0.9		%
		@ ± 15 V (± 5 %)	± 0.8		%
ε_L	Linearity error		< 0.2		%
			Typ	Maxi	
I_O	Offset current @ I_P = 0, T_A = 25°C			± 0.15	mA
I_{OT}	Temperature variation of I_O	0°C .. + 25°C	± 0.06	± 0.25	mA
		+ 25°C .. + 70°C	± 0.10	± 0.35	mA
t_r	Response time [1] to 90 % of I_{PN} step		40		µs

General data

T_A	Ambient operating temperature		0 .. + 70	°C
T_S	Ambient storage temperature		- 25 .. + 85	°C
R_P	Primary coil resistance @ T_A = 70°C		250	Ω
R_S	Secondary coil resistance @ T_A = 70°C		110	Ω
m	Mass		22	g
	Standards		EN 50178: 1997	

Note: [1] R_t = 25 kΩ (L/R constant, produced by the resistance and inductance of the primary circuit).

Features

- Closed loop (compensated) voltage transducer using the Hall effect
- Insulated plastic case recognized according to UL 94-V0.

Principle of use

- For voltage measurements, a current proportional to the measured voltage must be passed through an external resistor R_t which is selected by the user and installed in series with the primary circuit of the transducer.

Advantages

- Excellent accuracy
- Very good linearity
- Low thermal drift
- Low response time
- High bandwidth
- High immunity to external interference
- Low disturbance in common mode.

Applications

- AC variable speed drives and servo motor drives
- Static converters for DC motor drives
- Battery supplied applications
- Uninterruptible Power Supplies (UPS)
- Power supplies for welding applications.

Application domain

- Industrial.

LEM reserves the right to carry out modifications on its transducers, in order to improve them, without prior notice.

LEM

Voltage Transducer LV 25-P

Isolation characteristics

V_d	Rms voltage for AC isolation test, 50 Hz, 1 min	2.5 [2]	kV
$\hat{V}_w$	Impulse withstand voltage 1.2/50 µs	16	kV
		Mini	
dCp	Creepage distance	19.5	mm
dCl	Clearance distance	19.5	mm
CTI	Comparative Tracking Index (Group IIIa)	175	

Note: [2] Between primary and secondary.

Application examples

According to EN 50178 and IEC 61010-1 standards and following conditions:

- Over voltage category OV 3
- Pollution degree PD2
- Non-uniform field

	EN 50178	IEC 61010-1
dCp, dCl, $\hat{V}_w$	Rated isolation voltage	Nominal voltage
Single isolation	1600 V	1600 V
Reinforced isolation	800 V	800 V

Safety

This transducer must be used in electric/electronic equipment with respect to applicable standards and safety requirements in accordance with the manufacturer's operating instructions.

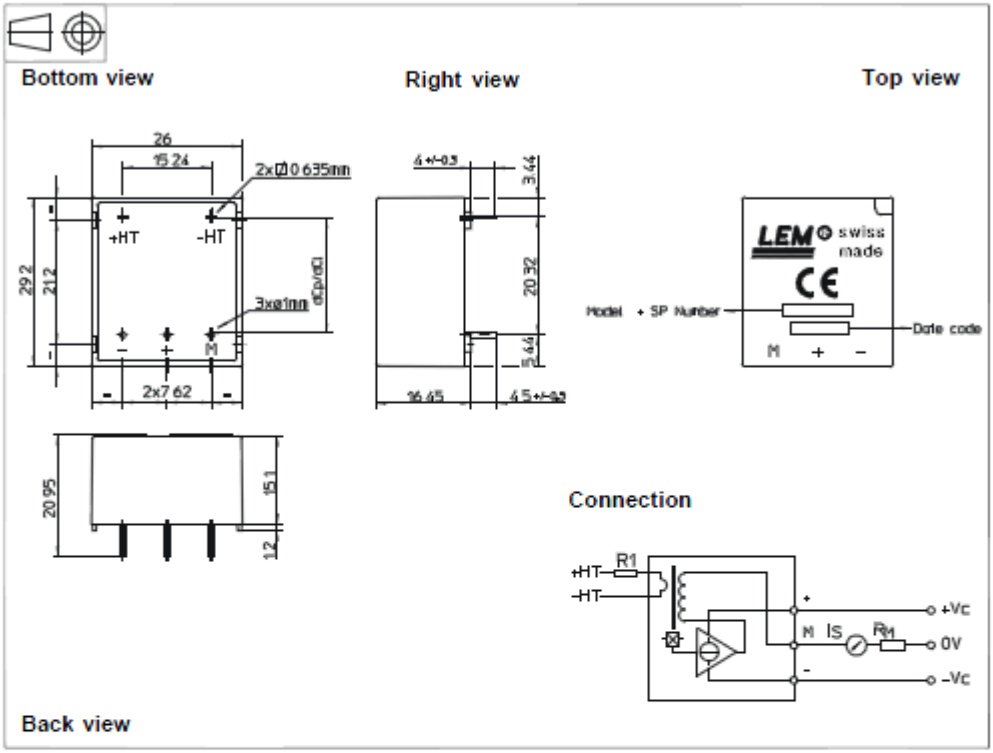
Caution, risk of electrical shock

When operating the transducer, certain parts of the module can carry hazardous voltage (eg. primary busbar, power supply).
Ignoring this warning can lead to injury and/or cause serious damage.
This transducer is a built-in device, whose conducting parts must be inaccessible after installation.
A protective housing or additional shield could be used.
Main supply must be able to be disconnected.

LEM reserves the right to carry out modifications on its transducers, in order to improve them, without prior notice.

LEM

Dimensions LV 25-P (in mm. 1 mm = 0.0394 inch)



Mechanical characteristics

• General tolerance	± 0.2 mm
• Fastening & connection of primary	2 pins 0.635 x 0.635 mm
• Fastening & connection of secondary	3 pins ∅ 1 mm
• Recommended PCB hole	1.2 mm

Remarks

- I_p is positive when V_p is applied on terminal +HT.
- This is a standard model. For different versions (supply voltages, turns ratios, unidirectional measurements...), please contact us.

Instructions for use of the voltage transducer model LV 25-P

Primary resistor R_1 : the transducer's optimum accuracy is obtained at the nominal primary current. As far as possible, R_1 should be calculated so that the nominal voltage to be measured corresponds to a primary current of 10 mA.

Example: Voltage to be measured V_{PN} = 250 V

a) R_1 = 25 kΩ / 2.5 W, I_p = 10 mA Accuracy = ± 0.8 % of V_{PN} (@ T_A = +25°C)
b) R_1 = 50 kΩ / 1.25 W, I_p = 5 mA Accuracy = ± 1.6 % of V_{PN} (@ T_A = +25°C)

Operating range (recommended) : taking into account the resistance of the primary windings (which must remain low compared to R_1 in order to keep thermal deviation as low as possible) and the isolation, this transducer is suitable for measuring nominal voltages from 10 to 500 V.

LEM reserves the right to carry out modifications on its transducers, in order to improve them, without prior notice.

APPENDIX C

LA 25-NP Current Transducer Datasheet

LEM

Current Transducer LA 25-NP

I_{PN} = 5-6-8-12-25 A

For the electronic measurement of currents : DC, AC, pulsed, mixed, with a galvanic isolation between the primary circuit (high power) and the secondary circuit (electronic circuit).

16080

Electrical data

I_{PN}	Primary nominal r.m.s. current			25			At
I_P	Primary current, measuring range			0 .. ± 36			At
R_M	Measuring resistance @		T_A = 70°C		T_A = 85°C		
			R_{Mmin}	R_{Mmax}	R_{Mmin}	R_{Mmax}	
	with ± 15 V	@ ± 25 At_{max}	100	320	100	315	Ω
		@ ± 36 At_{max}	100	190	100	185	Ω
I_{SN}	Secondary nominal r.m.s. current			25			mA
K_N	Conversion ratio			1-2-3-4-5 : 1000			
V_C	Supply voltage (± 5 %)			± 15			V
I_C	Current consumption			10 + I_S			mA
V_d	R.m.s. voltage for AC isolation test, 50 Hz, 1 mn			2.5			kV
V_b	R.m.s. rated voltage [1], safe separation			600			V
	basic isolation			1700			V

Accuracy - Dynamic performance data

X	Typical accuracy @ I_{PN} , T_A = 25°C		± 0.5		%
ε_L	Linearity error		< 0.2		%
			Typ	Max	
I_O	Offset current [2] @ I_P = 0, T_A = 25°C		± 0.05	± 0.15	mA
I_{OM}	Residual current [3] @ I_P = 0, after an overload of 3 x I_{PN}		± 0.05	± 0.15	mA
I_{OT}	Thermal drift of I_O	0°C .. + 25°C	± 0.06	± 0.25	mA
		+ 25°C .. + 70°C	± 0.10	± 0.35	mA
		- 25°C .. + 85°C		± 0.5	mA
		- 40°C .. + 85°C		± 1.2	mA
t_r	Response time [4] @ 90 % of I_{PN}		< 1		µs
di/dt	di/dt accurately followed		> 50		A/µs
f	Frequency bandwidth (- 1 dB)		DC .. 150		kHz

General data

T_A	Ambient operating temperature		- 40 .. + 85	°C
T_S	Ambient storage temperature		- 45 .. + 90	°C
R_P	Primary resistance per turn	@ T_A = 25°C	< 1.25	mΩ
R_S	Secondary coil resistance	@ T_A = 70°C	110	Ω
		@ T_A = 85°C	115	Ω
R_{is}	Isolation resistance @ 500 V, T_A = 25°C		> 1500	MΩ
m	Mass		22	g
	Standards		EN 50178 : 1997	

Notes : [1] Pollution class 2
[2] Measurement carried out after 15 mn functioning
[3] The result of the coercive field of the magnetic circuit
[4] With a di/dt of 100 A/µs.

Features

- Closed loop (compensated) multi-range current transducer using the Hall effect
- Insulated plastic case recognized according to UL 94-V0.

Advantages

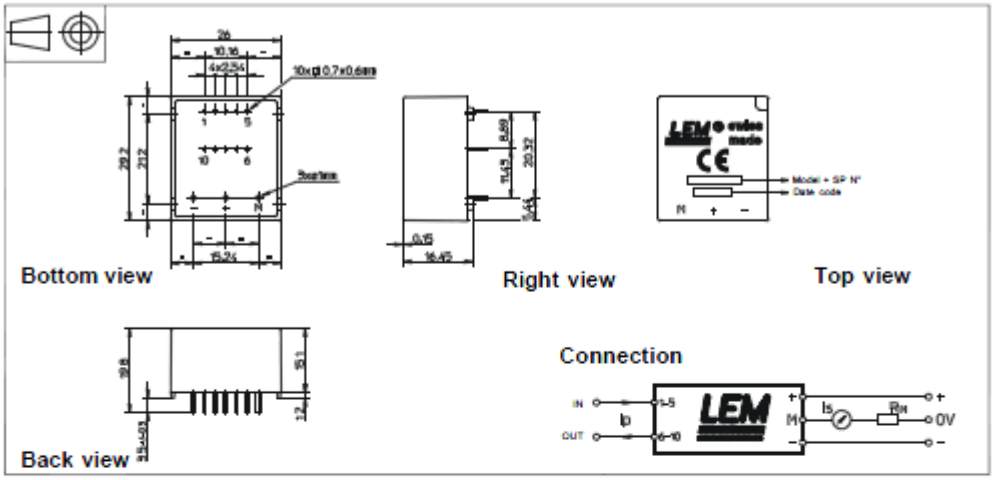
- Excellent accuracy
- Very good linearity
- Low temperature drift
- Optimized response time
- Wide frequency bandwidth
- No insertion losses
- High immunity to external interference
- Current overload capability.

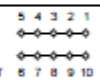
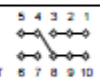
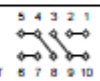
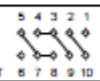
Applications

- AC variable speed drives and servo motor drives
- Static converters for DC motor drives
- Battery supplied applications
- Uninterruptible Power Supplies (UPS)
- Switched Mode Power Supplies (SMPS)
- Power supplies for welding applications.

LEM reserves the right to carry out modifications on its transducers, in order to improve them, without previous notice.

Dimensions LA 25-NP (in mm. 1 mm = 0.0394 inch)



Number of primary turns	Primary current nominal I_{PN} [A]	Primary current maximum I_P [A]	Nominal output current I_{SN} [mA]	Turns ratio K_N	Primary resistance R_P [mΩ]	Primary insertion Inductance L_P [µH]	Recommended connections
1	25	36	25	1/1000	0.3	0.023	
2	12	18	24	2/1000	1.1	0.09	
3	8	12	24	3/1000	2.5	0.21	
4	6	9	24	4/1000	4.4	0.37	
5	5	7	25	5/1000	6.3	0.58	

Mechanical characteristics

- General tolerance ± 0.2 mm
- Fastening & connection of primary 10 pins 0.7 x 0.6 mm
- Fastening & connection of secondary 3 pins ∅ 1 mm
- Recommended PCB hole 1.2 mm

Remarks

- I_s is positive when I_p flows from terminals 1, 2, 3, 4, 5 to terminals 10, 9, 8, 7, 6
- This is a standard model. For different versions (supply voltages, turns ratios, unidirectional measurements...), please contact us.

LEM reserves the right to carry out modifications on its transducers, in order to improve them, without previous notice.

APPENDIX D

SK40C Development Board User Manual

Cytron Technologies

SK40C

ENHANCED 40 PINS PIC START-UP KIT

User's Manual

V1.2

Dec 2010

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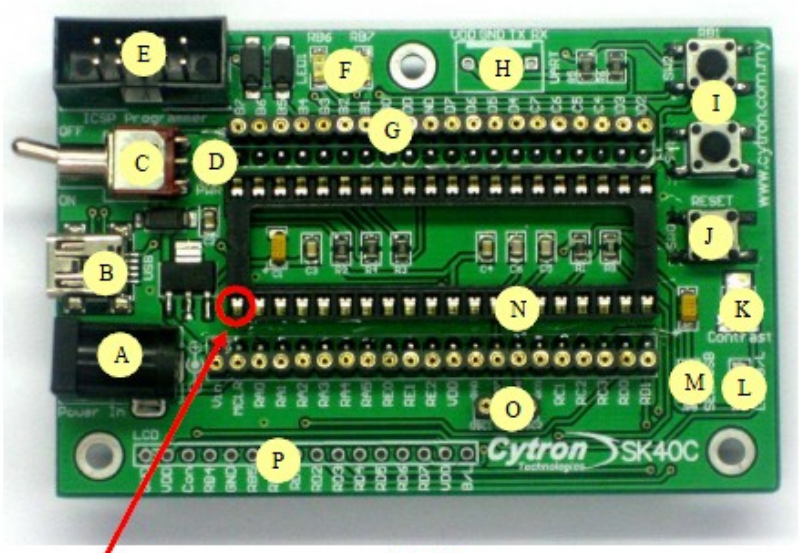
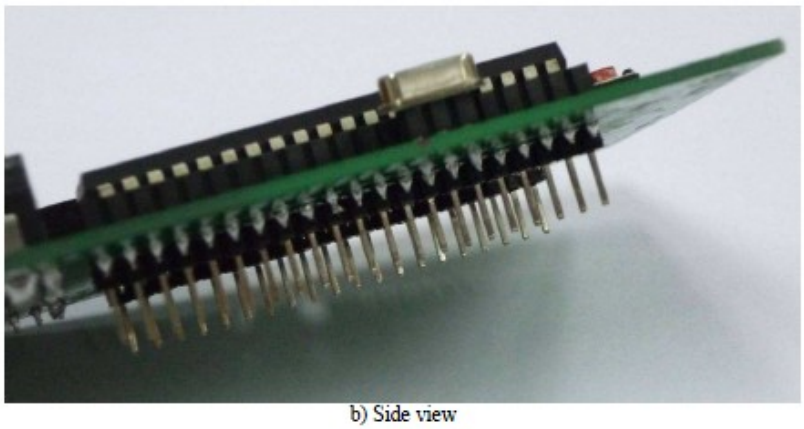
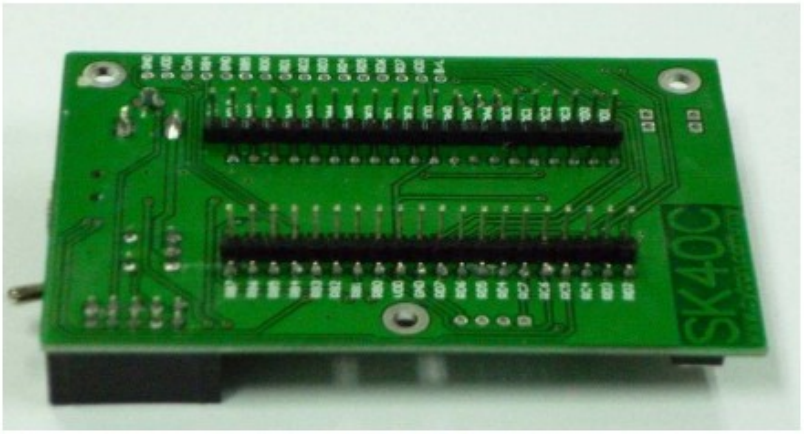
3. BOARD LAYOUT



a) Top View



b) Side view



c) Bottom view

Label	Function	Label	Function
A	DC power adaptor socket	I	Programmable Push Button
B	USB Connector	J	Reset button
C	Toggle Switch for power supply	K	LCD contrast
D	Power indicator LED	L	JP8 for LCD Backlight
E	Connector for UIC00A Programmer	M	JP9 for USB
F	LED Indicator	N	40 pin IC socket for PIC MCU
G	Header pin and turn pin	O	Turn pin for crystal
H	UART Connector	P	LCD Display

A – DC power adaptor socket for user to plug in DC adaptor. The input voltage should be ranged from 7 to 15V.

B – USB connector for communication between devices and a host controller (usually personal computers). This function is only valid for certain model of PIC microcontroller. Please refer to USB interface section. The power LED will light ON when the USB cable is connected.

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APPENDIX E

Firmware of PIC18F4550

Hardware profile:

```
#ifndef HARDWARE_PROFILE_PICDEM_FSUSB_H
#define HARDWARE_PROFILE_PICDEM_FSUSB_H


    #define tris_self_power     TRISAbits.TRISA2
    #if defined(USE_SELF_POWER_SENSE_IO)
    #define self_power          PORTAbits.RA2
    #else
    #define self_power          1
    #endif

    //#define USE_USB_BUS_SENSE_IO
    #define tris_usb_bus_sense  TRISAbits.TRISA1
    #if defined(USE_USB_BUS_SENSE_IO)
    #define USB_BUS_SENSE       PORTAbits.RA1
    #else
    #define USB_BUS_SENSE       1
    #endif



    #define PROGRAMMABLE_WITH_USB_HID_BOOTLOADER


       #define DEMO_BOARD PICDEM_FS_USB
    #define PICDEM_FS_USB
    #define CLOCK_FREQ 48000000



    /** SWITCH **/
    #define mInitAllSwitches()    TRISBbits.TRISB0=1;
    #define button                                  PORTBbits.RB0


    /** POT ***/

    #define mInitPOT1()
{TRISA=0b00000001;ADCON0=0b00000001;ADCON1=0x00;ADCON2=0b10010
100;}
#define mInitPOT2()
{TRISA=0b00000010;ADCON0=0b00000101;ADCON1=0x00;ADCON2=0b10010
100;}
```

```
    /** USB external transceiver *****/
    #define tris_usb_vpo        TRISBbits.TRISB3    // Output
    #define tris_usb_vmo        TRISBbits.TRISB2    // Output
    #define tris_usb_rcv        TRISAbits.TRISA4    // Input
    #define tris_usb_vp         TRISCbits.TRISC5    // Input
    #define tris_usb_vm         TRISCbits.TRISC4    // Input
    #define tris_usb_oe         TRISCbits.TRISC1    // Output

    #define tris_usb_suspnd     TRISAbits.TRISA3    // Output

    /** I/O pin definitions ************/
    #define INPUT_PIN 1
    #define OUTPUT_PIN 0
#endif  //HARDWARE_PROFILE_PICDEM_FSUSB_H
```

Main.c:

```
#ifndef MAIN_C
#define MAIN_C

#include "./USB/usb.h"
#include "HardwareProfile.h"
#include "./USB/usb_function_hid.h"

/** CONFIGURATION **********/
#if defined(PICDEM_FS_USB)
        #pragma config BORV     = 3
        #pragma config VREGEN   = ON
        #pragma config WDT      = OFF
        #pragma config WDTPS    = 32768
        #pragma config MCLRE    = ON
        #pragma config LPT1OSC  = OFF
        #pragma config PBADEN   = OFF
        #pragma config CCP2MX   = ON
        #pragma config STVREN   = ON
        #pragma config LVP      = OFF

        #pragma config PLLDIV   = 5
        #pragma config CPUDIV   = OSC1_PLL2
        #pragma config USBDIV   = 2
        #pragma config FOSC     = HSPLL_HS
        #pragma config FCMEN    = OFF
        #pragma config IESO     = OFF
        #pragma config PWRT     = OFF
        #pragma config BOR      = ON
```

```
//      #pragma config ICPRT    = OFF
        #pragma config XINST    = OFF
        #pragma config CP0      = OFF
        #pragma config CP1      = OFF
//      #pragma config CP2      = OFF
//      #pragma config CP3      = OFF
        #pragma config CPB      = OFF
//      #pragma config CPD      = OFF
        #pragma config WRT0     = OFF
        #pragma config WRT1     = OFF
//      #pragma config WRT2     = OFF
//      #pragma config WRT3     = OFF
        #pragma config WRTB     = OFF
        #pragma config WRTC     = OFF
//      #pragma config WRTD     = OFF
        #pragma config EBTR0    = OFF
        #pragma config EBTR1    = OFF
//      #pragma config EBTR2    = OFF
//      #pragma config EBTR3    = OFF
        #pragma config EBTRB    = OFF


#else
   #error No hardware board defined, see "HardwareProfile.h" and __FILE__
#endif

/** VARIABLES ****/
#pragma udata

#if defined(__18F14K50) || defined(__18F13K50) || defined(__18LF14K50) ||
defined(__18LF13K50)
   #pragma udata usbram2
#elif defined(__18F2455) || defined(__18F2550) || defined(__18F4455) ||
defined(__18F4550)\
   || defined(__18F2458) || defined(__18F2453) || defined(__18F4558) ||
defined(__18F4553)
   #pragma udata USB_VARIABLES=0x500

#else
   #pragma udata
#endif

unsigned char ReceivedDataBuffer[64];
unsigned char ToSendDataBuffer[64];
#pragma udata

USB_HANDLE USBOutHandle = 0;
USB_HANDLE USBInHandle = 0;
BOOL blinkStatusValid = TRUE;
```

```
/** PRIVATE PROTOTYPES ********/
void BlinkUSBStatus(void);
BOOL Switch2IsPressed(void);
BOOL Switch3IsPressed(void);
static void InitializeSystem(void);
void ProcessIO(void);
void UserInit(void);
void YourHighPriorityISRCode();
void YourLowPriorityISRCode();
void USBCBSendResume(void);
WORD_VAL ReadPOT(void);
void delay(unsigned long data);
int i=1;

/** VECTOR REMAPPING ********/
#if defined(__18CXX)

PROGRAMMABLE_WITH_USB_LEGACY_CUSTOM_CLASS_BOOTLOADER

        #if defined(PROGRAMMABLE_WITH_USB_HID_BOOTLOADER)
                #define REMAPPED_RESET_VECTOR_ADDRESS
        0x1000
                #define REMAPPED_HIGH_INTERRUPT_VECTOR_ADDRESS
        0x1008
                #define REMAPPED_LOW_INTERRUPT_VECTOR_ADDRESS
        0x1018
        #elif
defined(PROGRAMMABLE_WITH_USB_MCHPUSB_BOOTLOADER)
                #define REMAPPED_RESET_VECTOR_ADDRESS
        0x800
                #define REMAPPED_HIGH_INTERRUPT_VECTOR_ADDRESS
        0x808
                #define REMAPPED_LOW_INTERRUPT_VECTOR_ADDRESS
        0x818
        #else
                #define REMAPPED_RESET_VECTOR_ADDRESS
        0x00
                #define REMAPPED_HIGH_INTERRUPT_VECTOR_ADDRESS
        0x08
                #define REMAPPED_LOW_INTERRUPT_VECTOR_ADDRESS
        0x18
        #endif

        #if
defined(PROGRAMMABLE_WITH_USB_HID_BOOTLOADER)||defined(PROG
RAMMABLE_WITH_USB_MCHPUSB_BOOTLOADER)
        extern void _startup (void
        #pragma code REMAPPED_RESET_VECTOR =
REMAPPED_RESET_VECTOR_ADDRESS
```

```
        void _reset (void)
        {
            _asm goto _startup _endasm
        }
        #endif
        #pragma code REMAPPED_HIGH_INTERRUPT_VECTOR =
REMAPPED_HIGH_INTERRUPT_VECTOR_ADDRESS
        void Remapped_High_ISR (void)
        {
            _asm goto YourHighPriorityISRCode _endasm
        }
        #pragma code REMAPPED_LOW_INTERRUPT_VECTOR =
REMAPPED_LOW_INTERRUPT_VECTOR_ADDRESS
        void Remapped_Low_ISR (void)
        {
            _asm goto YourLowPriorityISRCode _endasm
        }

        #if
defined(PROGRAMMABLE_WITH_USB_HID_BOOTLOADER)||defined(PROG
RAMMABLE_WITH_USB_MCHPUSB_BOOTLOADER)


        #pragma code HIGH_INTERRUPT_VECTOR = 0x08
        void High_ISR (void)
        {
            _asm goto REMAPPED_HIGH_INTERRUPT_VECTOR_ADDRESS
_endasm
        }
        #pragma code LOW_INTERRUPT_VECTOR = 0x18
        void Low_ISR (void)
        {
            _asm goto REMAPPED_LOW_INTERRUPT_VECTOR_ADDRESS
_endasm
        }
        #endif  //end of "#if

defined(PROGRAMMABLE_WITH_USB_HID_BOOTLOADER)||defined(PROG
RAMMABLE_WITH_USB_LEGACY_CUSTOM_CLASS_BOOTLOADER)"

        #pragma code


                #pragma interrupt YourHighPriorityISRCode
        void YourHighPriorityISRCode()
        {

      #if defined(USB_INTERRUPT)
              USBDeviceTasks();
      #endif
```

```
        }                   #pragma interruptlow YourLowPriorityISRCode
        void YourLowPriorityISRCode()
        {


        }       #endif



/** DECLARATIONS ****/
#pragma code

/*********************************************************************
 * Function:        void main(void)
*********************************************************************/

#if defined(__18CXX)
void main(void)
#else
int main(void)
#endif
{
   InitializeSystem();

   #if defined(USB_INTERRUPT)
      USBDeviceAttach();
   #endif

   while(1)
   {
      #if defined(USB_POLLING)
                        USBDeviceTasks

      #endif



      ProcessIO();
   }
}

/*********************************************************************
*
 * Function:        static void InitializeSystem(void)
*********************************************************************/
static void InitializeSystem(void)
{
   #if (defined(__18CXX) & !defined(PIC18F87J50_PIM))
```

```
    ADCON1 |= 0x0F;                 // Default all pins to digital

  #endif


  #if defined(USE_USB_BUS_SENSE_IO)
  tris_usb_bus_sense = INPUT_PIN;
   #endif

  #if defined(USE_SELF_POWER_SENSE_IO)
  tris_self_power = INPUT_PIN;
  #endif

  UserInit();

  USBDeviceInit();
}



/********************************************************************
***********
 * Function:        void UserInit(void)
**/
void UserInit(void)
{


  //Initialize the push buttons
  mInitAllSwitches();

  USBOutHandle = 0;
  USBInHandle = 0;


}
/********************************************************************
*
 * Function:        void ProcessIO(void)
 *
*******************************************************************/

void ProcessIO(void)
{
while(button==0)
{
  if((USBDeviceState < CONFIGURED_STATE)||(USBSuspendControl==1))
return;
```

```
  if(!HIDRxHandleBusy(USBOutHandle))
   {
    switch(ReceivedDataBuffer[0])
    {


        case 0x37:      //Read POT command.  Uses ADC to measure an analog
voltage on one of the ANxx I/O pins, and returns the result to the host
            {



              WORD_VAL w;


                  if(!HIDTxHandleBusy(USBInHandle))
                  {
                                                if(i%2==1)
                                                {
                     mInitPOT1();
                     w = ReadPOT();

                                                ToSendDataBuffer[0] = 0x37;
        //Echo back to the host the command we are fulfilling in the first byte.  In this
case, the Read POT (analog voltage) command.
                                                ToSendDataBuffer[1] = w.v[0];
        //Measured analog voltage LSB
                                                ToSendDataBuffer[2] = w.v[1];
        //Measured analog voltage MSB

                     USBInHandle =
HIDTxPacket(HID_EP,(BYTE*)&ToSendDataBuffer[0],64);
                                                delay(1);
                                                }
                                                else if(i%2!=1)
                                                {
                                                 mInitPOT2();
                     w = ReadPOT();
                                                ToSendDataBuffer[0] = 0x37;
                                                ToSendDataBuffer[1] = w.v[0];
        //Measured analog voltage LSB
                                                ToSendDataBuffer[2] = w.v[1];
        //Measured analog voltage MSB

                     USBInHandle =
HIDTxPacket(HID_EP,(BYTE*)&ToSendDataBuffer[0],64);
```

```
                                                delay(1);
                                }


                                                }
                        }
                         break;


                                }
        USBOutHandle = HIDRxPacket(HID_EP,(BYTE*)&ReceivedDataBuffer,64);

}
}
}//end ProcessIO

/********************************************
 * Function:        WORD_VAL ReadPOT(void)

*********************************************/
WORD_VAL ReadPOT(void)
{


   WORD_VAL w;

   #if defined(__18CXX)

      if (i%2==1)
                  {
                  mInitPOT1();

      ADCON0bits.GO = 1;            // Start AD conversion
      while(ADCON0bits.NOT_DONE);     // Wait for conversion

      w.v[0] = ADRESL;
      w.v[1] = ADRESH;
                  i++;
                  delay(1);
                  }

                  else if (i%2!=1)
                  {
                  mInitPOT2();

      ADCON0bits.GO = 1;            // Start AD conversion
      while(ADCON0bits.NOT_DONE);     // Wait for conversion

      w.v[0] = ADRESL;
      w.v[1] = ADRESH+4;
```

```
                delay(1);
                i++;
                }



   #endif

   return w;

}



/********************************************************************
 * Function:        void USBCBSuspend(void)
********************************************************************/
void USBCBSuspend(void)
{

   #if defined(__C30__)

      _IPL = 1;
      USBSleepOnSuspend();
   #endif
}


/********************************************************************
 * Function:        void _USB1Interrupt(void)
********************************************************************/

#if 0
void __attribute__ ((interrupt)) _USB1Interrupt(void)
{
   #if !defined(self_powered)
      if(U1OTGIRbits.ACTVIF)
      {
         IEC5bits.USB1IE = 0;
         U1OTGIEbits.ACTVIE = 0;
         IFS5bits.USB1IF = 0;

         //USBClearInterruptFlag(USBActivityIFReg,USBActivityIFBitNum);
         USBClearInterruptFlag(USBIdleIFReg,USBIdleIFBitNum);
         //USBSuspendControl = 0;
      }
   #endif
}
#endif
```

```
/**********************************
 * Function:        void USBCBWakeFromSuspend(void)

*********************************************************/
void USBCBWakeFromSuspend(void)
{

}

/*********************************************************************
*
 * Function:        void USBCB_SOF_Handler(void)
*********************************************************************/

void USBCB_SOF_Handler(void)
{

}

/*********************************************************************
 * Function:        void USBCBErrorHandler(void)
*********************************************************************/
void USBCBErrorHandler(void)
{

}


/*********************************************************************
 * Function:        void USBCBCheckOtherReq(void)
*********************************************************************/

void USBCBCheckOtherReq(void)
{
   USBCheckHIDRequest();
}/


/*********************************************************************
 * Function:        void USBCBStdSetDscHandler(void)
*********************************************************************/
void USBCBStdSetDscHandler(void)
{
}

/*********************************************************************
 * Function:        void USBCBInitEP(void)
*********************************************************************/
void USBCBInitEP(void)
```

```
{


USBEnableEndpoint(HID_EP,USB_IN_ENABLED|USB_OUT_ENABLED|USB_
HANDSHAKE_ENABLED|USB_DISALLOW_SETUP);
   USBOutHandle = HIDRxPacket(HID_EP,(BYTE*)&ReceivedDataBuffer,64);
}

/******************************************************************
*
 * Function:        void USBCBSendResume(void)
 *
void USBCBSendResume(void)
{
   static WORD delay_count;
   if(USBGetRemoteWakeupStatus() == TRUE)
   {
      //Verify that the USB bus is in fact suspended, before we send
      //remote wakeup signalling.
      if(USBIsBusSuspended() == TRUE)
      {
         USBMaskInterrupts();

         //Clock switch to settings consistent with normal USB operation.
         USBCBWakeFromSuspend();
         USBSuspendControl = 0;
         USBBusIsSuspended = FALSE;  //So we don't execute this code again,
                           //until a new suspend condition is detected.

         //Section 7.1.7.7 of the USB 2.0 specifications indicates a USB
         //device must continuously see 5ms+ of idle on the bus, before it sends
         //remote wakeup signalling.  One way to be certain that this parameter
         //gets met, is to add a 2ms+ blocking delay here (2ms plus at
         //least 3ms from bus idle to USBIsBusSuspended() == TRUE, yeilds
         //5ms+ total delay since start of idle).
         delay_count = 3600U;
         do
         {
            delay_count--;
         }while(delay_count);

         //Now drive the resume K-state signalling onto the USB bus.
         USBResumeControl = 1;       // Start RESUME signaling
         delay_count = 1800U;        // Set RESUME line for 1-13 ms
         do
         {
            delay_count--;
         }while(delay_count);
         USBResumeControl = 0;       //Finished driving resume signalling
```

```
            USBUnmaskInterrupts();
        }
    }
}


/********************************************************************
 * Function:        BOOL USER_USB_CALLBACK_EVENT_HANDLER(
 *                  USB_EVENT event, void *pdata, WORD size)
********************************************************************/
BOOL USER_USB_CALLBACK_EVENT_HANDLER(USB_EVENT event, void
*pdata, WORD size)
{
    switch(event)
    {
        case EVENT_TRANSFER:
            //Add application specific callback task or callback function here if desired.
            break;
        case EVENT_SOF:
            USBCB_SOF_Handler();
            break;
        case EVENT_SUSPEND:
            USBCBSuspend();
            break;
        case EVENT_RESUME:
            USBCBWakeFromSuspend();
            break;
        case EVENT_CONFIGURED:
            USBCBInitEP();
            break;
        case EVENT_SET_DESCRIPTOR:
            USBCBStdSetDscHandler();
            break;
        case EVENT_EP0_REQUEST:
            USBCBCheckOtherReq();
            break;
        case EVENT_BUS_ERROR:
            USBCBErrorHandler();
            break;
        case EVENT_TRANSFER_TERMINATED:
            break;
        default:
            break;
    }
    return TRUE;
}

void delay(unsigned long data)
{
        for(;data>0;data--);
```

```
}

/** EOF main.c ************************************************/
#endif
```

APPENDIX F

Coding of Software Interface

Form1:

```
Imports Microsoft.Win32.SafeHandles
Imports System.Runtime.InteropServices
Imports System.Threading
Imports System.Data.SqlClient

Public Class Form1

    Dim DeviceIDToFind As String = "Vid_04d8&Pid_003f"



    Const DIGCF_PRESENT As UInteger = &H2
    Const DIGCF_DEVICEINTERFACE As UInteger = &H10
    Const FILE_ATTRIBUTE_NORMAL As Short = &H80
    Const INVALID_HANDLE_VALUE As Short = -1
    Const GENERIC_READ As UInteger = &H80000000
    Const GENERIC_WRITE As UInteger = &H40000000
    Const CREATE_NEW As UInteger = &H1
    Const CREATE_ALWAYS As UInteger = &H2
    Const OPEN_EXISTING As UInteger = &H3
    Const FILE_SHARE_READ As UInteger = &H1
    Const FILE_SHARE_WRITE As UInteger = &H2

    Const WM_DEVICECHANGE As UInteger = &H219
    Const DBT_DEVICEARRIVAL As UInteger = &H8000
    Const DBT_DEVICEREMOVEPENDING As UInteger = &H8003
    Const DBT_DEVICEREMOVECOMPLETE As UInteger = &H8004
    Const DBT_CONFIGCHANGED As UInteger = &H18

    Const DBT_DEVTYP_DEVICEINTERFACE As UInteger = &H5
    Const DEVICE_NOTIFY_WINDOW_HANDLE As UInteger = &H0
    Const ERROR_SUCCESS As UInteger = &H0
    Const ERROR_NO_MORE_ITEMS As UInteger = &H103
    Const SPDRP_HARDWAREID As UInteger = &H1


    Structure SP_DEVICE_INTERFACE_DATA
        Dim cbSize As UInteger
        Dim InterfaceClassGuid As Guid
        Dim Flags As UInteger
        Dim Reserved As IntPtr
    End Structure
```

```
    Structure SP_DEVICE_INTERFACE_DETAIL_DATA
        Dim cbSize As UInteger
        Dim DevicePath() As Char
    End Structure

    Structure SP_DEVINFO_DATA
        Dim cbSize As UInteger
        Dim ClassGuid As Guid
        Dim DevInst As UInteger
        Dim Reserved As IntPtr
    End Structure

    Structure DEV_BROADCAST_DEVICEINTERFACE
        Dim dbcc_size As UInteger
        Dim dbcc_devicetype As UInteger
        Dim dbcc_reserved As UInteger
        Dim dbcc_classguid As Guid
        Dim dbcc_name() As Char
    End Structure

    <DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
    Public Shared Function SetupDiGetClassDevs(ByRef ClassGuid As Guid, ByVal
Enumerator As IntPtr, ByVal hwndParent As IntPtr, ByVal Flags As UInteger) As
IntPtr
    End Function


    <DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
    Public Shared Function SetupDiEnumDeviceInterfaces(ByVal DeviceInfoSet As
IntPtr, ByVal DeviceInfoData As IntPtr, ByRef InterfaceClassGuid As Guid, ByVal
MemberIndex As UInteger, ByRef DeviceInterfaceData As
SP_DEVICE_INTERFACE_DATA) As Boolean
    End Function

    <DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
    Public Shared Function SetupDiDestroyDeviceInfoList(ByVal DeviceInfoSet As
IntPtr) As Boolean
    End Function

    <DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
    Public Shared Function SetupDiEnumDeviceInfo(ByVal DeviceInfoSet As IntPtr,
ByVal MemberIndex As UInteger, ByRef DeviceInterfaceData As
SP_DEVINFO_DATA) As Boolean
    End Function

    <DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
    Public Shared Function SetupDiGetDeviceRegistryProperty( _
        ByVal DeviceInfoSet As IntPtr, _
        ByRef DeviceInfoData As SP_DEVINFO_DATA, _
        ByVal dwProperty As UInteger, _
```

```
    ByRef PropertyRegDataType As UInteger, _
    ByVal PropertyBuffer As IntPtr, _
    ByVal PropertyBufferSize As UInteger, _
    ByRef RequiredSize As UInteger) As Boolean
End Function

<DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
Public Shared Function SetupDiGetDeviceInterfaceDetail( _
    ByVal DeviceInfoSet As IntPtr, _
    ByRef DeviceInterfaceData As SP_DEVICE_INTERFACE_DATA, _
    ByVal DeviceInterfaceDetailData As IntPtr, _
    ByVal DeviceInterfaceDetailDataSize As UInteger, _
    ByRef RequiredSize As UInteger, _
    ByVal DeviceInfoData As IntPtr) As Boolean
End Function

<DllImport("setupapi.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
Public Shared Function SetupDiGetDeviceInterfaceDetail( _
    ByVal DeviceInfoSet As IntPtr, _
    ByRef DeviceInterfaceData As SP_DEVICE_INTERFACE_DATA, _
    ByVal DeviceInterfaceDetailData As IntPtr, _
    ByVal DeviceInterfaceDetailDataSize As UInteger, _
    ByVal RequiredSize As IntPtr, _
    ByVal DeviceInfoData As IntPtr) As Boolean
End Function

<DllImport("user32.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
Public Shared Function RegisterDeviceNotification( _
    ByVal hRecipient As IntPtr, _
    ByVal NotificationFilter As IntPtr, _
    ByVal Flags As UInteger) As IntPtr
End Function

<DllImport("kernel32.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
Public Shared Function CreateFile( _
    ByVal FileName As String, _
    ByVal dwDesiredAccess As UInteger, _
    ByVal dwShareMode As UInteger, _
    ByVal lpSecurityAttributes As IntPtr, _
    ByVal dwCreationDisposition As UInteger, _
    ByVal dwFlagsAndAttributes As UInteger, _
    ByVal hTemplateFile As IntPtr) As SafeFileHandle
End Function

<DllImport("kernel32.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
Public Shared Function WriteFile( _
    ByVal hFile As SafeFileHandle, _
    ByVal Buffer As Byte(), _
    ByVal nNumberOfBytesToWrite As UInteger, _
    ByRef lpNumberOfBytesWritten As UInteger, _
```

```
        ByVal lpOverlapped As IntPtr) As Boolean
    End Function


    <DllImport("kernel32.dll", CharSet:=CharSet.Unicode, SetLastError:=True)> _
    Public Shared Function ReadFile( _
        ByVal hFile As SafeFileHandle, _
        ByVal lpBuffer As IntPtr, _
        ByVal nNumberOfBytesToWrite As UInteger, _
        ByRef lpNumberOfBytesRead As UInteger, _
        ByVal lpOverlapped As IntPtr) As Boolean
    End Function



    Dim InterfaceClassGuid As New Guid("4D1E55B2-F16F-11CF-88CB-
001111000030")

    Dim AttachedState As Boolean =
    Dim AttachedButBroken As Boolean = False

    Dim DetailedInterfaceDataStructure As New
SP_DEVICE_INTERFACE_DETAIL_DATA
    Dim ReadHandleToUSBDevice As SafeFileHandle
    Dim WriteHandleToUSBDevice As SafeFileHandle
    Dim DevicePath As String
    Dim ADCValue As Integer = 0

    Dim Mytime As Double
    Dim MyMiliseconds As Double
    Dim Mytime2 As Double
    Dim MyMiliseconds2 As Double
    Dim index As Integer
    Dim voltageValue As Double

    Dim num As Integer
    Dim voltageID As Integer
    Dim currentID As Integer
    Dim powerID As integer
    Dim idcounter As Integer
    Dim idcounterCurr As Integer
    Dim idcounterPow As Integer
    Dim randomTime As Double
    Dim randomValue As Double
    Dim ispause As Integer
    Dim MyMilisecondsA As Double
    Dim MyMilisecondsB As Double

    Dim intloop As Integer
    'current array
```

```
    Dim currentValue(10000000) As Double
    Dim currentMiliSecond1(10000000) As Double
    Dim currentMiliSecond2(10000000) As Double
    Dim CurrentArrindex As Integer

    'voltage array
    Dim voltagearrValue(10000000) As Double
    Dim voltagearrMilisecond1(10000000) As Double
    Dim voltagearrMilisecond2(10000000) As Double
    Dim voltageArrindex As Integer

    'power array
    Dim powerarrValue(10000000) As Double
    Dim powerarrMilisecond1(10000000) As Double
    Dim powerarrMilisecond2(10000000) As Double
    Dim powerArrindex As Integer


    Dim voltarrayIndex As Integer
    Dim currarrayIndex As Integer
    Dim highestvoltage As Double
    Dim highestvoltageTime As Double
    Dim highestcurrentTime As Double
    Dim highestcurrent As Double
    Dim startTime As DateTime
    Dim startTime2 As DateTime

    Dim powerFactor As Double
    Dim radian As Double
    Dim powerValue As Double
    Dim isTimerReset As Integer


   '//FUNCTION:       Form1_Load()

    Private Sub Form1_Load(ByVal sender As Object, ByVal e As System.EventArgs)
Handles Me.Load

        Me.PowerProfileTableAdapter.Fill(Me.Database1DataSet.powerProfile)
        Me.CurrentProfileTableAdapter.Fill(Me.Database1DataSet.currentProfile)
        Me.VoltageProfileTableAdapter.Fill(Me.Database1DataSet.voltageProfile)
        idcounter = Me.Database1DataSet.voltageProfile.Count()
        idcounterCurr = Me.Database1DataSet.currentProfile.Count()
        idcounterPow = Me.Database1DataSet.powerProfile.Count()


        highestvoltage = 0
        voltageID = idcounter
        currentID = idcounterCurr
        powerID = idcounterPow
```

```
        Dim DeviceBroadcastHeader As New
DEV_BROADCAST_DEVICEINTERFACE
        DeviceBroadcastHeader.dbcc_devicetype =
DBT_DEVTYP_DEVICEINTERFACE
        DeviceBroadcastHeader.dbcc_size = Marshal.SizeOf(DeviceBroadcastHeader)
        DeviceBroadcastHeader.dbcc_reserved = 0   '//Reserved says not to use...
        DeviceBroadcastHeader.dbcc_classguid = InterfaceClassGuid

        Dim pDeviceBroadcastHeader As IntPtr = IntPtr.Zero  '
        pDeviceBroadcastHeader =
Marshal.AllocHGlobal(Marshal.SizeOf(DeviceBroadcastHeader
Marshal.StructureToPtr(DeviceBroadcastHeader, pDeviceBroadcastHeader, False)
RegisterDeviceNotification(Me.Handle, pDeviceBroadcastHeader,
DEVICE_NOTIFY_WINDOW_HANDLE)
        Marshal.FreeHGlobal(pDeviceBroadcastHeader)

        If CheckIfPresentAndGetUSBDevicePath() Then
            Dim ErrorStatusWrite As UInteger
            Dim ErrorStatusRead As UInteger

            WriteHandleToUSBDevice = CreateFile(DevicePath, GENERIC_WRITE,
FILE_SHARE_READ Or FILE_SHARE_WRITE, IntPtr.Zero, OPEN_EXISTING,
0, IntPtr.Zero)
            ErrorStatusWrite = Marshal.GetLastWin32Error()
            ReadHandleToUSBDevice = CreateFile(DevicePath, GENERIC_READ,
FILE_SHARE_READ Or FILE_SHARE_WRITE, IntPtr.Zero, OPEN_EXISTING,
0, IntPtr.Zero)
            ErrorStatusRead = Marshal.GetLastWin32Error()


            If (ErrorStatusWrite = ERROR_SUCCESS) And (ErrorStatusRead =
ERROR_SUCCESS) Then
                AttachedState = True
               AttachedButBroken = False
                StatusBox_txtbx.Text = "Device Found, AttachedState = TRUE"
            Else
                AttachedState = False
                AttachedButBroken = True
                If ErrorStatusWrite = ERROR_SUCCESS Then
                    WriteHandleToUSBDevice.Close()
                End If

                If ErrorStatusRead = ERROR_SUCCESS Then
                    ReadHandleToUSBDevice.Close()
                End If
            End If
        Else
            AttachedState = False
```

```
            AttachedButBroken = False
        End If


        If AttachedState = True Then
            StatusBox_txtbx.Text = "Device Found, AttachedState = TRUE"
        Else
            StatusBox_txtbx.Text = "Device not found, verify connect/correct firmware"
        End If


        ReadWriteThread.RunWorkerAsync()
    End Sub



    '//FUNCTION:       WndProc()
    Protected Overrides Sub WndProc(ByRef m As System.Windows.Forms.Message)
        If m.Msg = WM_DEVICECHANGE Then
            If ((m.WParam = DBT_DEVICEARRIVAL) Or (m.WParam =
DBT_DEVICEREMOVEPENDING) Or (m.WParam =
DBT_DEVICEREMOVECOMPLETE) Or (m.WParam =
DBT_CONFIGCHANGED)) Then
                If CheckIfPresentAndGetUSBDevicePath() = True
                    If ((AttachedState = False) Or (AttachedButBroken = True)) Then
                        Dim ErrorStatusRead As UInteger
                        Dim ErrorStatusWrite As UInteger


                        WriteHandleToUSBDevice = CreateFile(DevicePath,
GENERIC_WRITE, FILE_SHARE_READ Or FILE_SHARE_WRITE, IntPtr.Zero,
OPEN_EXISTING, 0, IntPtr.Zero)
                        ErrorStatusWrite = Marshal.GetLastWin32Error()
                        ReadHandleToUSBDevice = CreateFile(DevicePath,
GENERIC_READ, FILE_SHARE_READ Or FILE_SHARE_WRITE, IntPtr.Zero,
OPEN_EXISTING, 0, IntPtr.Zero)
                        ErrorStatusRead = Marshal.GetLastWin32Error()


                        If ((ErrorStatusWrite = ERROR_SUCCESS) And (ErrorStatusRead =
ERROR_SUCCESS)) Then
                            AttachedState =
                            AttachedButBroken = False
                            StatusBox_txtbx.Text = "Device Found, AttachedState = TRUE"
                        Else
                            AttachedState = False
                            AttachedButBroken = True
                            If ErrorStatusWrite = ERROR_SUCCESS Then
                                WriteHandleToUSBDevice.Close()
                            End If
```

```
                    If ErrorStatusRead = ERROR_SUCCESS Then
                        ReadHandleToUSBDevice.Close()
                    End If
                End If
            End If

        Else
            If AttachedState = True Then
                AttachedState = False
                WriteHandleToUSBDevice.Close()
                ReadHandleToUSBDevice.Close()
            End If
            AttachedState = False
            AttachedButBroken = False
        End If
    End If
End If
MyBase.WndProc(m)
End Sub



'//FUNCTION: CheckIfPresentAndGetUSBDevicePath()

Private Function CheckIfPresentAndGetUSBDevicePath() As Boolean
    Try
        Dim DeviceInfoTable As IntPtr = IntPtr.Zero
        Dim InterfaceDataStructure As New SP_DEVICE_INTERFACE_DATA()
        Dim DetailedInterfaceDataStructure As New
SP_DEVICE_INTERFACE_DETAIL_DATA()
        Dim DevInfoData As New SP_DEVINFO_DATA()
        Dim InterfaceIndex As UInteger = 0
        Dim dwRegType As UInteger = 0
        Dim dwRegSize As UInteger = 0
        Dim dwRegSize2 As UInteger = 0
        Dim StructureSize As UInteger = 0
        Dim PropertyValueBuffer As IntPtr = IntPtr.Zero
        Dim MatchFound As Boolean = False
        Dim ErrorStatus As UInteger = 0
        Dim LoopCounter As UInteger = 0
        Dim DeviceIDToFind As String = "Vid_04d8&Pid_003f"

        DeviceInfoTable = SetupDiGetClassDevs(InterfaceClassGuid, IntPtr.Zero,
IntPtr.Zero, DIGCF_PRESENT Or DIGCF_DEVICEINTERFACE)
        If DeviceInfoTable <> IntPtr.Zero Then
            While True
                InterfaceDataStructure.cbSize = Marshal.SizeOf(InterfaceDataStructure)
```

```
            If SetupDiEnumDeviceInterfaces(DeviceInfoTable, IntPtr.Zero,
InterfaceClassGuid, InterfaceIndex, InterfaceDataStructure) Then
                ErrorStatus = Marshal.GetLastWin32Error()

                If ErrorStatus = ERROR_NO_MORE_ITEMS
                   SetupDiDestroyDeviceInfoList(DeviceInfoTable
                   Return False
                End If

                DevInfoData.cbSize = Marshal.SizeOf(DevInfoData)
                SetupDiEnumDeviceInfo(DeviceInfoTable, InterfaceIndex,
DevInfoData)

                SetupDiGetDeviceRegistryProperty(DeviceInfoTable, DevInfoData,
SPDRP_HARDWAREID, dwRegType, IntPtr.Zero, 0, dwRegSize)

                PropertyValueBuffer = Marshal.AllocHGlobal(CType(dwRegSize,
IntPtr))


                SetupDiGetDeviceRegistryProperty(DeviceInfoTable, DevInfoData,
SPDRP_HARDWAREID, dwRegType, PropertyValueBuffer, dwRegSize,
dwRegSize2)
                ErrorStatus = Marshal.GetLastWin32Error()

                Dim DeviceIDFromRegistry As String
                DeviceIDFromRegistry =
Marshal.PtrToStringUni(PropertyValueBuffer)
                Marshal.FreeHGlobal(PropertyValueBuffer
                DeviceIDFromRegistry = DeviceIDFromRegistry.ToLowerInvariant()
                DeviceIDToFind = DeviceIDToFind.ToLowerInvariant()

                MatchFound = DeviceIDFromRegistry.Contains(DeviceIDToFind)

                If MatchFound Then

                   DetailedInterfaceDataStructure.cbSize =
Marshal.SizeOf(DetailedInterfaceDataStructure)
                   SetupDiGetDeviceInterfaceDetail(DeviceInfoTable,
InterfaceDataStructure, IntPtr.Zero, 0, StructureSize, IntPtr.Zero)

                   Dim pUnmanagedDetailedInterfaceDataStructure As IntPtr =
IntPtr.Zero    .
                   pUnmanagedDetailedInterfaceDataStructure =
Marshal.AllocHGlobal(CType(StructureSize, IntPtr
DetailedInterfaceDataStructure.cbSize =
Marshal.StructureToPtr(DetailedInterfaceDataStructure,
pUnmanagedDetailedInterfaceDataStructure, False)
```

```
                    If SetupDiGetDeviceInterfaceDetail(DeviceInfoTable,
InterfaceDataStructure, pUnmanagedDetailedInterfaceDataStructure, StructureSize,
IntPtr.Zero, IntPtr.Zero) Then
                        Dim pToDevicePath As IntPtr
                        pToDevicePath =
pUnmanagedDetailedInterfaceDataStructure.ToInt32() +
DevicePath = Marshal.PtrToStringUni(pToDevicePath)
                        SetupDiDestroyDeviceInfoList(DeviceInfoTable)
Marshal.FreeHGlobal(pUnmanagedDetailedInterfaceDataStructure
            Return True
                    Else
                        Dim ErrorCode As UInteger = Marshal.GetLastWin32Error()
                        SetupDiDestroyDeviceInfoList(DeviceInfoTable

Marshal.FreeHGlobal(pUnmanagedDetailedInterfaceDataStructure)
                        Return False
                    End If
                End If

                InterfaceIndex = InterfaceIndex + 1

                LoopCounter = LoopCounter + 1
                If LoopCounter = 10000000

                    Return False
                End If
            Else

                ErrorStatus = Marshal.GetLastWin32Error()
                SetupDiDestroyDeviceInfoList(DeviceInfoTable
                Return False
            End If

        End While
    End If
    Return False
  Catch ex As Exception

    Return False
  End Try
End Function


'//FUNCTION:       FormUpdateTimer_Tick()


Private Sub FormUpdateTimer_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles FormUpdateTimer.Tick
```

```
        If AttachedState = True Then

            StatusBox_txtbx.Text = "Device Found: AttachedState = TRUE"


        End If



        If (AttachedState = False) Or (AttachedButBroken = True) Then

            StatusBox_txtbx.Text = "Device Not Detected: Verify Connection/Correct
Firmware"

            ADCValue = 0

        End If

        If (ispause = 0) Then

            voltagetxtbox.Text = ADCValue
        End If

            End Sub




    '//FUNCTION:       ReadWriteThread_DoWork()


    Private Sub ReadWriteThread_DoWork(ByVal sender As System.Object, ByVal e
As System.ComponentModel.DoWorkEventArgs) Handles
ReadWriteThread.DoWork

        Dim OUTBuffer(65) As
        Dim INBuffer(65) As
        Dim BytesWritten As UInteger = 0
        Dim BytesRead As UInteger = 0
        Dim ErrorStatus As UInteger


        While True
            Try

                If AttachedState = True Then
```

```
                OUTBuffer(0) = 0    '//The first byte is the "Report ID" and does not get
sent over the USB bus, unless the HID report descriptor uses Report IDs.  Assume
the HID report descriptor does not, then always set this byte to 0
                OUTBuffer(1) = &H37 '//READ_POT command (see the firmware
source code), gets 10-bit ADC Value
                '//Initialize the rest of the 64-byte packet to "0xFF".  Binary '1' bits do
not use as much power, and do not cause as much EMI
                '//when they move across the USB cable.  USB traffic is "NRZI"
encoded, where '1' bits do not cause the D+/D- signals to toggle states.
                '//This initialization is not strictly necessary however.
                For i As Integer = 2 To 65
                    OUTBuffer(i) = &HFF
                Next

                '//To get the ADCValue, first, we send a packet with our "READ_POT"
command in it.
                If WriteFile(WriteHandleToUSBDevice, OUTBuffer, 65, BytesWritten,
IntPtr.Zero) Then
                    INBuffer(0) = 0
                    '//Now get the response packet from the firmware.

                    If ReadFileManagedBuffer(ReadHandleToUSBDevice, INBuffer, 65,
BytesRead, IntPtr.Zero) Then
                        '//INBuffer[0] is the report ID, which we don't care about.
                        '//INBuffer[1] is an echo back of the command (see microcontroller
firmware).
                        '//INBuffer[2] and INBuffer[3] contains the ADC value (see
microcontroller firmware).

                        If INBuffer(1) = &H37 Then
                            ADCValue = (CType(INBuffer(3), UInteger) << 8) + INBuffer(2)
'//Need to reformat the data from two unsigned chars into one unsigned int.
                        End If

                    End If
                Else
                    ErrorStatus = Marshal.GetLastWin32Error()
                End If

            End If


        Catch ex As Exception
            '//Exceptions can occur during the read or write operations.  For example,
            '//exceptions may occur if for instance the USB device is physically
unplugged
            '//from the host while the above read/write functions are executing.

            '//Don't need to do anything special in this case.  The application will
automatically
```

```
            '//re-establish communications based on the global AttachedState boolean
variable used
            '//in conjunction with the WM_DEVICECHANGE messages to
dyanmically respond to Plug and Play
            '//USB connection events.
        End Try


    End While


End Sub




'//FUNCTION: ReadFileManagedBuffer()



Private Function ReadFileManagedBuffer(ByVal hFile As SafeFileHandle, ByRef
INBuffer() As Byte, ByVal nNumberOfBytesToRead As UInteger, ByRef
lpNumberOfBytesRead As UInteger, ByVal lpOverlapped As IntPtr) As Boolean
    Dim pINBuffer As IntPtr = IntPtr.Zero

    Try
        pINBuffer = Marshal.AllocHGlobal(CType(nNumberOfBytesToRead,
Integer))     '//Allocate some unmanged RAM for the receive data buffer.

        If ReadFile(hFile, pINBuffer, nNumberOfBytesToRead,
lpNumberOfBytesRead, lpOverlapped) Then
            Marshal.Copy(pINBuffer, INBuffer, 0, lpNumberOfBytesRead)   '//Copy
over the data from unmanged memory into the managed byte[] INBuffer
            Marshal.FreeHGlobal(pINBuffer)
            Return True
        Else
            Marshal.FreeHGlobal(pINBuffer)
            Return False
        End If

    Catch ex As Exception
        If pINBuffer <> IntPtr.Zero Then
            Marshal.FreeHGlobal(pINBuffer)
            Return False
        End If
    End Try
End Function
```

```
    Private Sub progressBar1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)

    End Sub

    Private Sub Label1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)

    End Sub

    Private Sub StatusBox_lbl_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles StatusBox_lbl.Click

    End Sub

    Private Sub VoltageProfileBindingNavigatorSaveItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
VoltageProfileBindingNavigatorSaveItem.Click
        Me.Validate()
        Me.VoltageProfileBindingSource.EndEdit()
        Me.TableAdapterManager.UpdateAll(Me.Database1DataSet)

    End Sub

    Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer1.Tick

        Dim span As TimeSpan = DateTime.Now.Subtract(startTime)
        Label1.Text = span.Minutes.ToString & ":" & _
        span.Seconds.ToString & "." & span.Milliseconds
        Mytime = span.TotalMilliseconds
        MyMiliseconds = Mytime / 1000

    End Sub

    Private Sub voltagetxtbox_TextChanged(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles voltagetxtbox.TextChanged

        powerID = powerID + 1

        If (voltagetxtbox.Text < 1024) Then

            voltageID = voltageID + 1
            volttextbox.Text = ((((voltagetxtbox.Text / 1024 * 5)) / 200 / 2.5 * 39000) /
System.Math.Sqrt(2)) * 1.1
            voltageValue = volttextbox.Text
            If (voltageValue > highestvoltage) Then
                highestvoltage = voltageValue
```

```
            highestvoltageTime = MyMiliseconds2
        End If

        voltagetime.Text = highestvoltageTime
        highestVoltageTxt.Text = highestvoltage

        voltagearrValue(voltageArrindex) = voltageValue
        voltagearrMilisecond1(voltageArrindex) = MyMiliseconds
        voltagearrMilisecond2(voltageArrindex) = MyMiliseconds2
        voltageArrindex = voltageArrindex + 1



    Else

        currentID = currentID + 1

        currtextbox.Text = (((voltagetxtbox.Text - 1024) / 1024 * 5 / 150 * 500) /
System.Math.Sqrt(2)) * 1.1

        voltageValue = currtextbox.Text

        If (voltageValue > highestcurrent) Then

            highestcurrent = voltageValue
            highestcurrentTime = MyMiliseconds2
        End If

        highestCurrenttxt.Text = highestcurrent
        currentTimetext.Text = highestcurrentTime

        currentValue(CurrentArrindex) = voltageValue
        currentMiliSecond1(CurrentArrindex) = MyMiliseconds 'normal time
        currentMiliSecond2(CurrentArrindex) = MyMiliseconds2 ' graph time
        CurrentArrindex = CurrentArrindex + 1


    End If

    powerarrValue(powerArrindex) = powerValue
    powerarrMilisecond1(powerArrindex) = MyMiliseconds
    powerarrMilisecond2(powerArrindex) = MyMiliseconds2
    powerArrindex = powerArrindex + 1


    timetext.Text = MyMiliseconds
End Sub
```

```
    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click

        idcounter = Me.Database1DataSet.voltageProfile.Count()
        idcounterCurr = Me.Database1DataSet.currentProfile.Count()
        idcounterPow = Me.Database1DataSet.powerProfile.Count()

        'voltage delete
        For intloopIndex As Integer = 0 To idcounter
            Me.VoltageProfileTableAdapter.Delete(intloopIndex)

        Next intloopIndex

        'current delete
        For intloop As Integer = 0 To idcounterCurr
            Me.CurrentProfileTableAdapter.Delete(intloop)
        Next intloop

        For intloopPower As Integer = 0 To idcounterPow
            Me.PowerProfileTableAdapter.Delete(intloopPower)
        Next intloopPower


        'fill the data to data grid view
        Me.VoltageProfileTableAdapter.Fill(Me.Database1DataSet.voltageProfile)
        Me.CurrentProfileTableAdapter.Fill(Me.Database1DataSet.currentProfile)
        Me.PowerProfileTableAdapter.Fill(Me.Database1DataSet.powerProfile)

        'reset id
        voltageID = 0
        currentID = 0
        powerID = 0
        highestcurrent = 0
        highestvoltage = 0


        Array.Clear(voltagearrValue, 0, voltageArrindex)
        Array.Clear(voltagearrMilisecond1, 0, voltageArrindex)
        Array.Clear(voltagearrMilisecond2, 0, voltageArrindex)


        Array.Clear(currentValue, 0, CurrentArrindex)
        Array.Clear(currentMiliSecond1, 0, CurrentArrindex)
        Array.Clear(currentMiliSecond2, 0, CurrentArrindex)

        Array.Clear(powerarrValue, 0, powerArrindex)
        Array.Clear(powerarrMilisecond2, 0, powerArrindex)


        voltageArrindex = 0
```

```
        powerArrindex = 0
        CurrentArrindex = 0


    End Sub

    Private Sub PictureBox1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles PictureBox1.Click
        Form2.Show()

    End Sub

    Private Sub PictureBox2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles PictureBox2.Click
        Form3.Show()

    End Sub

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button3.Click


        If (Timer2.Enabled) Then

            Button3.Text = "Restart"
            ispause = 1


            Timer1.Stop()
            Timer2.Stop()
        Else
            startTime = DateTime.Now()
            startTime2 = DateTime.Now()
            Me.Text = "Click to Stop"
            Button3.Text = "Stop"
            ispause = 0
            Timer1.Start()
            Timer2.Start()
        End If
    End Sub



    Private Sub CurrentTextBox_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles CurrentTextBox.TextChanged

    End Sub

    Private Sub VoltageTextBox_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles VoltageTextBox.TextChanged
```

```
    End Sub

    Private Sub Stopwatch_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        startTime = DateTime.Now()
        startTime2 = DateTime.Now()
        Timer1.Start()
        Timer2.Start()
    End Sub

    Private Sub highestVoltageTxt_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles highestVoltageTxt.TextChanged

         Dim radian As Double
        radian = (highestcurrentTime - highestvoltageTime) / 0.02 * 360 * Math.PI /
180

        powerFactor = System.Math.Cos(radian)
        powerFactortxt.text = powerFactor
    End Sub

    Private Sub highestCurrenttxt_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles highestCurrenttxt.TextChanged
        Dim radian As Double
        radian = (highestcurrentTime - highestvoltageTime) / 0.02 * 360 * Math.PI /
180

        powerFactor = System.Math.Cos(radian)
        powerFactortxt.Text = powerFactor
    End Sub

    Private Sub powerFactortxt_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles powerFactortxt.TextChanged


        powerValue = highestvoltage * highestcurrent * powerFactor
        powerText.Text = powerValue


    End Sub

    Private Sub Timer2_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer2.Tick

        Dim span2 As TimeSpan = DateTime.Now.Subtract(startTime2)
        Label2.Text = span2.Minutes.ToString & ":" & _
        span2.Seconds.ToString & "." & span2.Milliseconds
        Mytime2 = span2.TotalMilliseconds
        MyMiliseconds2 = Mytime2 / 1000
```

```
    End Sub

    Private Sub PictureBox3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles PictureBox3.Click
        Form4.Show()

    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        ispause = 1
        '#####################################################################
        '#########################voltage insert value
########################
        '#####################################################################


        For intloopInsertvolt As Integer = 0 To voltageArrindex + 1
            If (voltagearrMilisecond2(intloopInsertvolt) > 0) Then
                Me.VoltageProfileTableAdapter.Insert(intloopInsertvolt,
voltagearrMilisecond1(intloopInsertvolt), voltagearrValue(intloopInsertvolt),
voltagearrMilisecond2(intloopInsertvolt))
            End If
            If (powerarrMilisecond2(intloopInsertvolt) > 0) Then
                Me.PowerProfileTableAdapter.Insert(intloopInsertvolt,
powerarrMilisecond1(intloopInsertvolt), powerarrValue(intloopInsertvolt))
            End If
            If (currentMiliSecond2(intloopInsertvolt) > 0) Then
                Me.CurrentProfileTableAdapter.Insert(intloopInsertvolt,
currentMiliSecond1(intloopInsertvolt), currentValue(intloopInsertvolt),
currentMiliSecond2(intloopInsertvolt))
            End If

        Next intloopInsertvolt



        'fill the data to data grid view
        Me.VoltageProfileTableAdapter.Fill(Me.Database1DataSet.voltageProfile)
        Me.CurrentProfileTableAdapter.Fill(Me.Database1DataSet.currentProfile)
        Me.PowerProfileTableAdapter.Fill(Me.Database1DataSet.powerProfile)
        MessageBox.Show("Insert finish")


    End Sub
End Class
```

Form2:

```
Imports System.Data
Imports System.Data.SqlClient

Imports System.Windows.Forms.DataVisualization.Charting

Public Class Form2

    Private Sub Form2_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        'TODO: This line of code loads data into the 'Database1DataSet.voltageProfile'
table. You can move, or remove it, as needed.
        Me.VoltageProfileTableAdapter.Fill(Me.Database1DataSet.voltageProfile)

        Dim random As New Random()

        Dim ChartArea1 As ChartArea = New ChartArea()
        Dim Legend1 As Legend = New Legend()
        Dim Series1 As Series = New Series()
        Dim Chart1 = New Chart()
        Me.Controls.Add(Chart1)

        ChartArea1.Name = "ChartArea1"
        Chart1.ChartAreas.Add(ChartArea1)
        Legend1.Name = "Legend1"
        Chart1.Legends.Add(Legend1)
        Chart1.Location = New System.Drawing.Point(13, 13)
        Chart1.Name = "Chart1"
        Series1.ChartArea = "ChartArea1"
        Series1.Legend = "Legend1"
        Series1.Name = "Series1"
        Series1.ChartType = SeriesChartType.Spline

        Chart1.Series.Add(Series1)
        Chart1.Size = New System.Drawing.Size(1000, 800)
        'Chart1.TabIndex = 0
        'Chart1.Text = "Chart1"

        Chart1.Series("Series1").XValueMember = "timeGraph"
        Chart1.Series("Series1").YValueMembers = "voltage"

        Chart1.DataSource = Me.Database1DataSet.voltageProfile


    End Sub
```

```
    Private Sub VoltageProfileBindingNavigatorSaveItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
VoltageProfileBindingNavigatorSaveItem.Click
        Me.Validate()
        Me.VoltageProfileBindingSource.EndEdit()
        Me.TableAdapterManager.UpdateAll(Me.Database1DataSet)

    End Sub
End Class
```

Form 3:

```
Imports System.Data
Imports System.Data.SqlClient

Imports System.Windows.Forms.DataVisualization.Charting


Public Class Form3

    Private Sub CurrentProfileBindingNavigatorSaveItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
CurrentProfileBindingNavigatorSaveItem.Click
        Me.Validate()
        Me.CurrentProfileBindingSource.EndEdit()
        Me.TableAdapterManager.UpdateAll(Me.Database1DataSet)

    End Sub

    Private Sub Form3_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        'TODO: This line of code loads data into the 'Database1DataSet.currentProfile'
table. You can move, or remove it, as needed.
        Me.CurrentProfileTableAdapter.Fill(Me.Database1DataSet.currentProfile)
        Dim random As New Random()

        Dim ChartArea1 As ChartArea = New ChartArea()
        Dim Legend1 As Legend = New Legend()
        Dim Series1 As Series = New Series()
        Dim Chart1 = New Chart()
        Me.Controls.Add(Chart1)

        ChartArea1.Name = "ChartArea1"
        Chart1.ChartAreas.Add(ChartArea1)
```

```
        Legend1.Name = "Legend1"
        Chart1.Legends.Add(Legend1)
        Chart1.Location = New System.Drawing.Point(13, 13)
        Chart1.Name = "Chart1"
        Series1.ChartArea = "ChartArea1"
        Series1.Legend = "Legend1"
        Series1.Name = "Series1"
        Series1.ChartType = SeriesChartType.Spline

        Chart1.Series.Add(Series1)
        Chart1.Size = New System.Drawing.Size(1000, 800)
        'Chart1.TabIndex = 0
        'Chart1.Text = "Chart1"

        Chart1.Series("Series1").XValueMember = "timeGraph"
        Chart1.Series("Series1").YValueMembers = "current"

        Chart1.DataSource = Me.Database1DataSet.currentProfile
    End Sub
End Class
```

Form 4:

```
Imports System.Data
Imports System.Data.SqlClient

Imports System.Windows.Forms.DataVisualization.Charting

Public Class Form4

    Private Sub Form4_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        'TODO: This line of code loads data into the 'Database1DataSet.powerProfile'
table. You can move, or remove it, as needed.
        Me.PowerProfileTableAdapter.Fill(Me.Database1DataSet.powerProfile)


        Dim ChartArea1 As ChartArea = New ChartArea()
        Dim Legend1 As Legend = New Legend()
        Dim Series1 As Series = New Series()
        Dim Chart1 = New Chart()
        Me.Controls.Add(Chart1)

        ChartArea1.Name = "ChartArea1"
        Chart1.ChartAreas.Add(ChartArea1)
        Legend1.Name = "Legend1"
```

```
        Chart1.Legends.Add(Legend1)
        Chart1.Location = New System.Drawing.Point(13, 13)
        Chart1.Name = "Chart1"
        Series1.ChartArea = "ChartArea1"
        Series1.Legend = "Legend1"
        Series1.Name = "Series1"
        Series1.ChartType = SeriesChartType.Spline

        Chart1.Series.Add(Series1)
        Chart1.Size = New System.Drawing.Size(1000, 800)
        'Chart1.TabIndex = 0
        'Chart1.Text = "Chart1"

        Chart1.Series("Series1").XValueMember = "time"
        Chart1.Series("Series1").YValueMembers = "power"

        Chart1.DataSource = Me.Database1DataSet.powerProfile

    End Sub

    Private Sub PowerProfileBindingNavigatorSaveItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
PowerProfileBindingNavigatorSaveItem.Click
        Me.Validate()
        Me.PowerProfileBindingSource.EndEdit()
        Me.TableAdapterManager.UpdateAll(Me.Database1DataSet)

    End Sub
End Class
```